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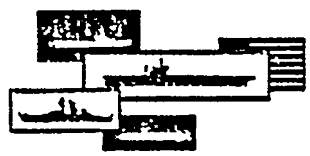
NSRP
1985 Ship Production Symposium
Volume II

September 11-I3, 1985
Hyatt Regency Hotel
Long Beach, California

"Moving Ahead with Implemention of Advanced Technology"

National Shipbuilding Research Program (NSRP)

1985 SHIP PRODUCTION SYMPOSIUM



Sponsored by:

Society of Naval Architects and Marine Engineers
Ship Production Committee

""SEPTEMBER 1l-13.1985""

LONG BEACH, CALIFORNIA
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SESSION TOPICS:

- **Flexible Manufacturing**
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- **Surface Preparation and Painting**
- **Education and Training**
- **Industrial Engineering**
- **Human Resource Innovation**
- **Welding**
- **Design/Production Integration**
- **Standards and Specifications**
- **Outfitting and Production Aids**
- **Navy Ship Production**

PREFACE

The NSRP 1985 Ship Production Symposium was held in Long Beach, California on September 11-13, 1985. It was sponsored by the Society of Naval Architects and Marine Engineers and the Ship Production Committee.

The thrust of the program was "Moving Ahead With Implementation of Advanced Technology" and focused on the ongoing projects of the panels of the Ship Production Committee. Each panel was responsible for one of the symposium sessions and selected the 2-4 papers to be presented within that session. An additional session was added to cover Navy Production and Ship Repair.

The symposium was a project of the SP-9 Education Panel and was financed through SP-9 with financial contributions from each of the other panels. It is one of many projects managed and cost-shared by The University of Michigan for the National Shipbuilding Research Program. The Program is a cooperative effort of the Maritime Administration's Office of Advanced Ship Development, the U.S. Navy, the U.S. shipbuilding industry, and selected academic institutions.

The personal efforts of many people vitally interested in and committed to the ship production industry and research made this symposium an informative, successful experience. Grateful thanks to each of you.

Wendy Barhydt
1985 Symposium Manager

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PANEL SP-7

WELDING

Benjamin C. Howser
Newport News Shipbuilding

Chairman

SNAME/SPC Welding Panel SP-7

Fiscal Year 1984 Overview

The Welding Panel, SP-7 completed another year of activity September 30, 1984. I believe that it can be safely said that we have had a good year and in the next few minutes, I will go over our panel activities for the year, let you know what is presently happening and give you the panel outlook for the future.

At the beginning of Fiscal Year (FY)' 1984, the SP-7 Panel had six projects in progress and seven projects approved and funded but not underway. During the course of the year, one of the projects - Evaluation of the Unimation "Apprentice" Robot - was terminated prior to completion because preliminary studies indicated that any potential benefit this equipment may have had for shipbuilding welding had been far surpassed by existing robot welding technology.

Two others of the six projects in progress were completed in FY 1984 and reports were printed and distributed. These were:

1. Out-of-Position Welding of 5000 Series Aluminum Alloys Using Pulse GMAW Power Sources.

   This project successfully demonstrated that full penetration butt welds could be made out-of-position and from one side of the plate. The welds were made with basic "off-the-shelf" welding power sources (costing less than $5,000), wire feeders, guns and accessories currently available to all U.S. shipyards. These

projects were performed, utilizing the pulse welding mode of the power sources, on 5000 series aluminum alloy sheets and plates for marine applications. The welds met all specification inspection requirements for type and thickness of material; i.e. visual, radiographic and dye penetrant examination. Welding procedure qualification data was developed such that these techniques might be implemented in other shipyards as an improved cost effective approach to hull, superstructure, sheet metal and piping fabrication. It is also anticipated that fabricators of surface effect ships, hydrofoils and crew boats may find applications for some of the information developed.

2. <u>Study of Fitting and Fairing Aids of U.S. Shipyards</u>

This study was undertaken in recognition of the need for more accurate fitting in shipbuilding. Attempts to automate the higher deposition welding processes have met with limited success because the quality of fitting practiced in shipbuilding was and is not satisfactory for automatic welding without frequent operator intervention.

Inconsistent root gaps, non-parallel joint edges and uneven plate surfaces do not lend themselves to automatic welding, and many of the benefits that can be obtained as a result of

automation are lost by virtue of an operator having to be in constant attendance. This fact becomes even more apparent when robots are introduced into the welding operation and it becomes immediately obvious that the quality of the weld is almost totally dependent on the quality of the fit-up.

There are at least two options to solving the problem of fitting inaccuracy as it pertains to automatic and robotic welding. The first and most obvious is to improve the accuracy and quality of fitting. This option, while perhaps not readily achievable due to a number of circumstances, is the most desirable in the long run. Robot evaluation projects at the Los Angeles Division of Todd Shipyards indicate that when the fitters were required to meet tolerances satisfactory for robot welding, the entire welding program benefitted and continued to benefit even after the robot evaluation was completed.

Contrary to how it may have sounded up to this point, this paper is not intended as a blanket indictment of fitting personnel and practices in U.S. shipyards. It is recognized that, at the very best, fitting is a difficult task. Shipbuilding materials are often less than ideal to work with, having been subjected to conditions beyond the fitter's control but which, nonetheless, become his responsibility. For example, problems 'start with the way materials are made. Stresses from rolling mills and heat treatments can cause problems during the fabrication process.

Mill tolerances are often excessive and can add up during fabrication and may result in localized stress and distortion.

Improper handling of such materials as plate, pipe, shapes and castings can have a detrimental effect on surface condition and dimensional accuracy. Incorrect and poorly performed burning and cutting operations contribute greatly to the inaccuracy of assemblies. The heat of cutting may cause shrinkage and other distortions which must be monitored and offset. Edge conditions must be held to specification or fitting and welding will be increased. Deformation also results when materials are mechanically formed on rolls and similar equipment. This causes stresses which will in turn cause distortion when the stresses are relieved by welding, cutting and heat treatments.

These problems encountered during fabrication of ship assemblies are well known and shipyards in the U.S. deal with them continually. Because these problems are shared by all shipyards, this study was initiated to document those devices and methods used by U.S. shipbuilders to combat these problems-and, where feasible, to recommend areas for improvement. The overall objective was to review the methodology for the use of fitting and fairing aids and assess the potential for improving the accuracy of fitting. This would result in reduced costs for materials, energy and labor by introducing the most advanced available techniques suitable to the individual yards. The need for greater accuracy in fitting and fairing to increase production cannot be over emphasized. This can only be achieved through the use of fitting to support welding rather than the use of welding to compensate for inaccurate fitting.

A second option, while not as desirable as improved fit-up, has become necessary to accommodate automatic and robotic welding. Due to the cyclic nature of shipbuilding and the highs and lows of employment, it is almost guaranteed that shipyards will have inexperienced burners and fitters; therefore, poor fit-UP. To compensate for this, programs are underway to develop systems that will overcome poorly fit-up weld joints. One of these, a through the arc sensing, microprocessor controlled seam tracker is the subject of an SP-7 project and will be reported on later in this meeting in a paper entitled "Tracking System for Automatic Welding".

In addition to these projects, the SP-7 panel had two other projects in progress which were initiated prior to FY 1984 and will be complete in Calendar Year (CY) 1985. One of these is entitled "Multi-Consumable Guide Electroslag Welding" (ESW) and has as its objective the development of the ESW process for joining 4" to 24" thick low carbon steel castings. Cast steel hull structural components have always presented unique problems for welding, fabrication and repair. With conventional multi-pass welding processes, the requirements for joint configuration and preparation; preheating and interpass temperature control methods; weld sequencing for distortion control and in-process dimensional checks, not only become fabrication bottlenecks but also critical welding process controlling factors.

The multi-consumable guide electroslag welding process provides an alternative to the above problems. This process can best be described as a welding technique which is based on the

generation of heat by passing electrical current through molten slag. Its advantages include high deposition rate; high quality weld deposit; minimal joint preparation and fit-up and minimal angular distortion.

Even though the U.S. shipbuilding industry has used this' process, very little work has been done in the area of welding thick members. The application of the process would be directed toward the joining of rudder arms, shaft strut arms and other thick casting pieces. The electroslag welding process would significantly reduce the cost of weld fabrication and repair of these items.

Another project in progress in FY 1984 and complete in CY 1985 is entitled "Examination of Candidate Steels for High Heat Input Welding". This project has evolved as an offshoot of a much larger, earlier effort and came about in the following manner.

Modernization of shipbuilding methods and facilities which occurred during the 1970's in both foreign and U.S. shipyards, was directed toward improvements in welding technology. Higher deposition rates offered by automatic and semiautomatic processes offer substantial cost savings in many areas of shipyard welding.

Processes such as electrogas and electroslag welding of vertical side shell and bulkhead butts produce welds which offer better appearance and uniformity at substantially lower cost than manual stick electrode welding. Unfortunately, high heat input at comparatively low travel speeds adversely affects the toughness properties in both the weld and the heat affected zone

(HAZ). Charpy V-notch tests are the basis of evaluation used ABS and many other classification organizations to evaluate toughness. In view of the relatively large and increasing extent of these welds, it was felt that a more definite criteria of toughness should be established. Development of a project to establish tests other than Charpy V-notch to evaluate toughness; i.e. drop weight, dynamic tear and explosion bulge tests, entailed welding specimens of different grades and different chemical compositions of steel to be used in the testing procedure. Based on small scale impact test results, some of these steels appeared to not be significantly degraded by high heat input welding, and it was felt they would warrant full scale examination and testing. These facts became evident during previous studies made by the American Bureau of Shipping. It was recommended that these candidate steels be evaluated and subjected to a full range of weldability, nondestructive and destructive tests to determine their suitability for high heat input welding. The' benefits to be realized by shipbuilders through the use of steels that would allow the increased use of these high deposition processes were sufficient to convince the panel that the project should be undertaken. It is now complete and a report of the project will appear in the written proceedings of this Symposium.

In addition to the aforementioned projects, the Welding Panel has eight projects in progress which were initiated in FY 1984, and are still incomplete. - One of these, "Evaluate the Benefits and Determine the Feasibility of Twisted Electrode GMA

and FCA Narrow Gap Welding" is sufficiently advanced such that a paper will be presented during this meeting. A second project which will be printed in the Symposium proceedings is entitled "Evaluate the Benefits of New High Strength Low Alloy (HSLA) Steels".

Three of the other six are initial efforts which are on schedule, within budget, with completion expected during CY 1985. They are:

(1) Cored Wire for Submerged Arc Welding;

(2) Benefits of Low Moisture Electrodes and

(3) Bulk Welding of High Strength Quenched and Tempered Steels.

The other three in progress are Phase II efforts of recently completed projects and are extensions of the original projects or are examinations in greater depth of the results of those projects. They are:

(1) Visual Reference Standards for Weld Surface Conditions

(2) Acceptance Standards for NDT of Welds Not Covered By Classification

(3) Tracking System for Automatic Welding.

'The preceding summary is an accurate account of the technical effort of our panel and one which we believe is effectively addressing some of the more pressing welding problems facing the U.S. shipbuilding industry.

The objectives and purpose of all of the panels that make up the National Shipbuilding Research Program are to engage in projects whose results will reduce the time and the cost of building ships. There are no written guidelines on how to do this; it is simply left up to the particular panel of industry respresentatives to determine how this can best be accomplished.

In the case of the SP-7 Panel, the collective knowledge, experience and wisdom of the panel members has been and is being utilized to develop projects that will provide the greatest measures of productivity increases and schedule reductions for the present and for the immediate future. These include application and implementation of currently available technology which provides immediate, quantifiable benefits and tend to exclude research and development of technology with only unknown or estimated benefits.

Successful completion and implementation of the projects previously described would provide immediate worthwhile benefits. For example, because of the strength and toughness required of the steel used in today's ship construction and repair, preheating is required prior to welding. This must be done to reduce the susceptibility of the weld and base material from cracking as a result of hydrogen entrapment during welding. The Welding Panel has two projects, each with a very different approach and scope of work, but whose ultimate objective is the same; the elimination of preheating prior to welding.

One of these is an evaluation of welding performed with extremely low moisture electrodes which reduces the likelihood of hydrogen pickup during the welding operation. The second involves evaluation of high strength low alloy (HSLA) steels which are not susceptible to hydrogen induced cracking and, therefore, generally do not require preheating. It is hoped that successful results from this project would allow substitution of these steels for some of those presently being used which require preheat, thereby eliminating the need for this very costly requirement. (It has been estimated that the elimination of the preheating requirement would result in a savings of one million dollars per ship on certain type Navy ships.)

Another example of evaluating and implementing existing technology with high potential for cost/schedule reduction is the previously mentioned project to further develop, refine and qualify a procedure for welding thick section carbon steel castings with the consumable guide tube electroslag welding process. A relatively recent technology breakthrough in steel manufacture shows early promise of overcoming the drawbacks of the electroslag process. It has been discovered that careful application and control of the thermo-mechanical processes involved in steel making produces steel that is not easily damaged by heat input and can be produced in the strength and toughness levels that-make it attractive for construction and repair of naval ships. The ability to use the electroslag automatic plate crawler and the consumable guide tube electroslag welding processes without limitations would make it very

attractive from the shipbuilder's point of view. The SP-7 Panel has a project to begin evaluation of some of these steels; subjecting them to the full range of destructive and nondestructive tests.

These are just some of the examples of developing and implementing existing technology rather than concentrating on the exotic processes such as electron beam and laser welding. This is not to say that our intent is to deliberately ignore these processes because we believe that they are fine for some types of industrial welding. On the other hand, shipbuilding methods do not offer sufficient opportunities for utilizing these processes to provide a reasonable payback for the tremendous capital outlay for equipment, dedicated facilities, training, etc. that would be necessary to make them function.

In the case of robots, the Welding Panel is engaged in projects designed to overcome the largest single drawback to robotized shipbuilding welding; poor fit-up. Until this shortcoming is overcome or a successful means developed to compensate for it, fully automatic robotic welding will not become a reality in shipbuilding.

For the future, it is our plan to keep abreast of the everchanging technology of shipbuilding and the effect of that technology on the art and science of welding. We cannot simply concentrate on the welding processes themselves, however, but must design and plan for welding more effectively. We must encourage and insist on the application of fitting and fabrication methods that provide the quality of fit-up necessary

for utilization of the highest deposition processes in the automatic and robotic modes. Work must continue in the development of materials; i.e. base materials, filler materials, fluxes, etc. that are compatible with the high deposition processes. These must be evaluated and subjected to the full range of weldability, nondestructive and destructive tests to prove their suitability for intended service. Continued emphasis is necessary on the development of the most effective and least disruptive inspection methods that will satisfy the requirements and conform to the standards of the various code-making bodies. We must continue to provide the technical requirements for a well trained work force as well as making sure that all levels of management are made and kept aware of the complexities of welding and the potential that it has to reduce costs when applied correctly and effectively.

Last but not least, continued emphasis on the application of the welding processes, methods and techniques that are known and have proven satisfactory. At the same time to keep informed as to the latest improvements in new methods and techniques for their possible application to shipbuilding welding.

Thank You.

PUGET SOUND NAVAL SHIPYARD
Welding Engineering Division
Bremerton, Washington

Interim Report

EVALUATION OF THE USEABILITY AND BENEFITS OF TWIST WIRE GMAW & FCAW NARROW GAP WELDING 1984-1985

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Code 138.2

Presented By

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ABSTRACT

Puget Sound Naval Shipyard is evaluating and developing the twisted wire narrow gap joints and reduced bevel weld joints for the shipbuilding industry. Test and evaluation work is being accomplished with twisted solid wire and twisted flux cored arc weld on carbon steel, low alloy steels (ASTM-302B) and quenched and temper steels (HY-80). Weld joint design tolerances, welding parameters tracking systems and weld joint irregularities have been evaluated with both twisted FCAW and solid welding electrodes. All test welds have been accomplished on two and three inch thick base metals. The following elements of the electrode quality were found to be critical for depositing sound metal: uniformity of the twist; tightness of the twist; smoothness of the wire; amounts of residual stress; prevention of looping; and the amount of helix.

INTRODUCTION

Puget Sound Naval Shipyard is evaluating twist wire narrow gap welding for applications in the shipbuilding industry. This evaluation is being accomplished for the Ship Productivity Panel Number Seven of the National Ship Building Research Program. The work has included the evaluation of both twist solid electrode and twist flux cored electrode. At the present time there is no routine, satisfactory welding technique in use in the United States for narrow gap welding of 1" to 3" thick marine steels. As compared to what could be achieved with twist wire narrow gap welding, the conventional welding processes in use today require large amounts of flame cutting for joint preparation, longer arc times, more filler metal and result in greater weld distortion. Currently heavy fabricated metal for ship hulls, decks, inserts, foundations, etc. requires large bevel angles for equipment access and electrode manipulation to obtain high quality welds. The twist wire welding process appears to provide an excellent alternative to expensive and time consuming conventional welding processes. The twist wire welding process gives good side wall fusion in narrow gap weld joints by the inherent weaving or rotating arc. Also, the necessary equipment for twist wire welding is not complicated.

Although the study is not yet complete, there are some basic known requirements that must be complied with for successful narrow gap welding. These include the following:

1) Quality control of wire twisting is very important. Details such as twist angle, looping, helix, residual torsion stress, serrations and tightness of twists must be monitored.
2) Weld joints that are too narrow will lead to solidification cracking and weld joints that are too wide will cause lack of fusion.

Both large diameter solid wire (2mm) and large diameter flux cored wire (3/32") will produce high quality welds in material up to 3 inches thick. Flux cored arc welding appears to have some advantage over solid wire in that it is less parameter sensitive, welds wider gaps, wets more easily, and is more easily shielded. However, slag must be removed from each weld pass.

WELD DEFECTS AND CAUSES

To evaluate the useability of the twist wire welding process it is first important to understand the causes of weld defects which are unique to one pass per layer narrow gap welding. As expected with the narrow gap joint configuration, a major problem is lack of sidewall fusion. The twist wire process elimates lack of fusion by using magnetic arc deflections and arc rotation to direct the arc force more toward the joint sidewalls. Figure 1 schematically shows how the arc is alternately generated from two solid wires of the conventional twist wire process and the resulting intermittent arc rotation. Arc stabilizers in flux cored twist wire allows an arc to be generated from both wires at all times resulting in continuous arc rotation and a dramatically lower depth-to-width ratio D/W.

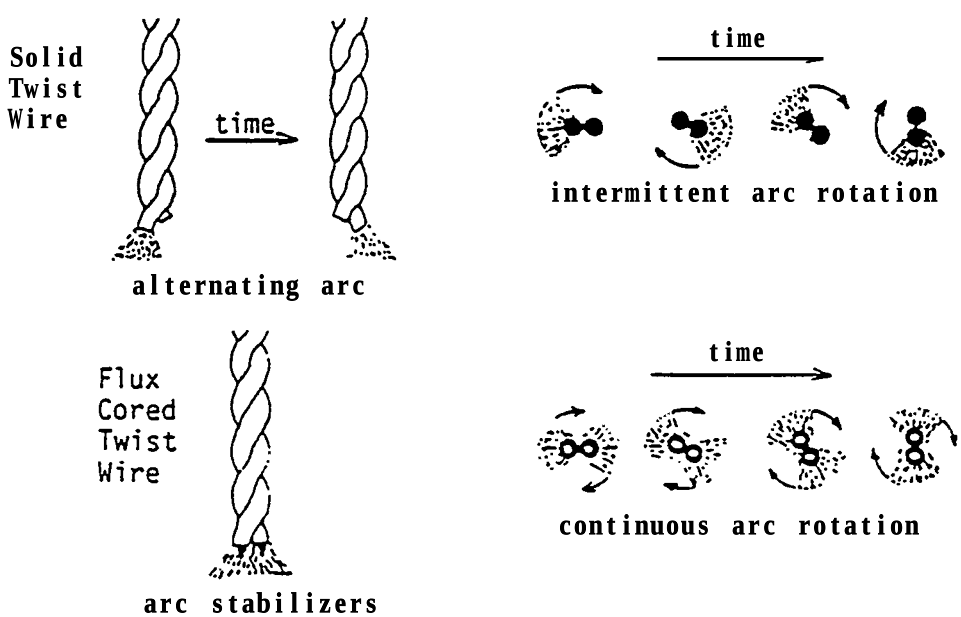


Figure 1. Arc deflections

The weld cross sectional bead shape is a very important factor to consider in eliminating sidewall lack of fusion. Figure 2 shows how the uniform bead shape eliminates lack of fusion. The desired bead shape of Figure 2b, as achieved by the twist wire welding process, has a deeper sidewall penetration throughout the weld cross section and a more uniform penetration depthwise than the bead shape of Figure 2a for single wire GMAW narrow gap welding. Even if the bead shape of Figure 2a has a greater penetration in the location W, the bead shape of Figure 2b is more desirable since it eliminates lack of fusion by increasing the sidewall penetration in the critical location W_1.

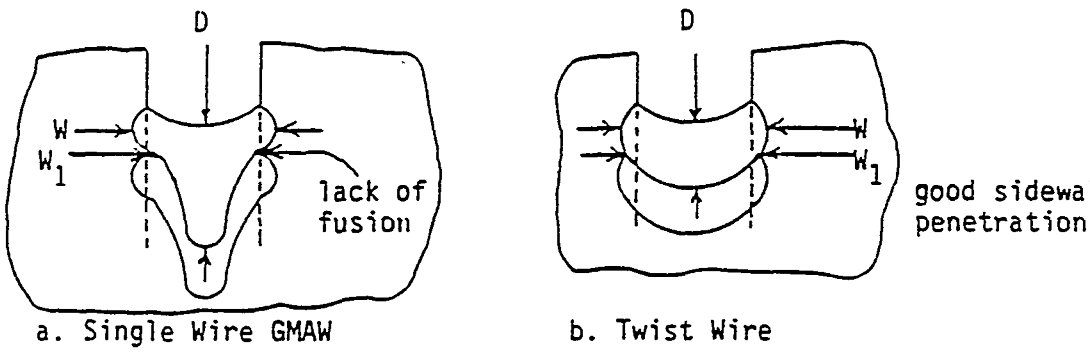
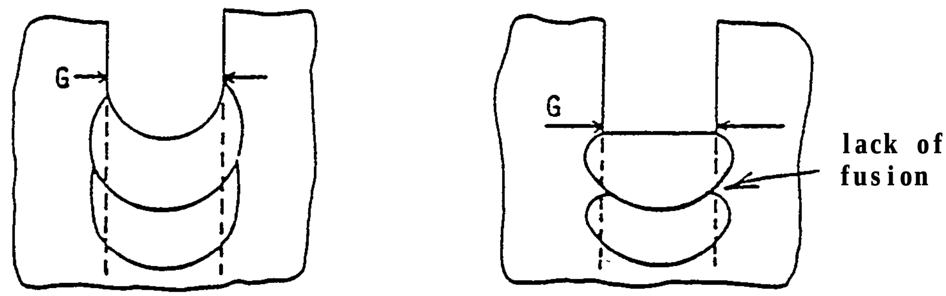


Figure 2. Bead shape

A concave bead surface is also necessary to eliminate lack of fusion at the weld joint interface of the subsequent weld layer. Once the proper cross-sectional bead shape of Figure 2b is obtained, developing the flat bead surface of Figure 3b by increasing the gap width becomes the factor which 1 limits how wide the gap width G can be. The fiat bead surface of Figure 3b will cause lack of sidewall fusion at the bottom of the next weld bead.



a. Sidewall wetting

b: NO wetting

Figure 3. Bead surface

Figure 4 shows the relationship between solidification cracking and the depth to width ratio D/W of mild steel weld beads deposited under the high restraint conditions of narrow gap welds in thick plate.

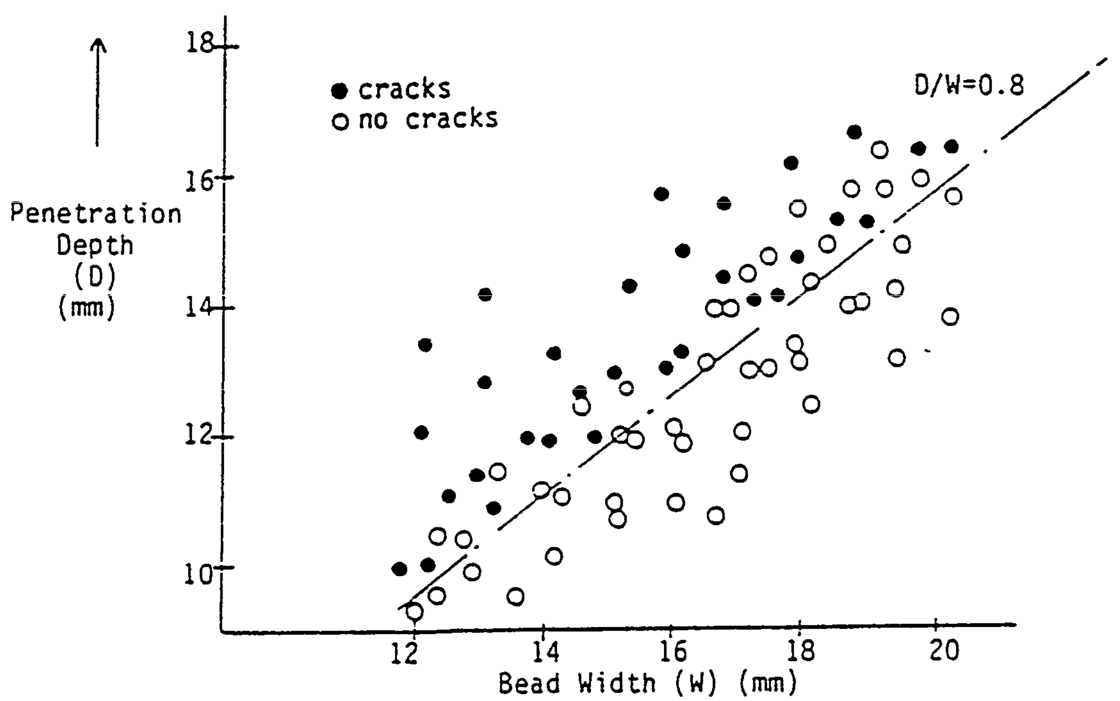


Figure 4* Conditions causing solidification cracking

Figure 4 shows that when D/W is greater than 0.8 there is a high chance of. solidification cracking. Experience has shown that when the base material

* ref. 2

or filler metal is manganese molybdenum or in general has a higher carbon equivalent than mild steel solidification cracking may occur at a lower D/W ratio. On the other hand, when twist MIL-100S-1 electrode (Mn,Ni,Mo) is used or when a plate with less restraint is welded the D/W ratio can be higher without cracking. For the sake of analysis, 0.8 was used as the maximum acceptable D/W ratio with the understanding that this value may need to be adjusted for the specific material type and weld restraint conditions.

The dendritic grain growth and segregation pattern versus the gap width is shown in Figure 5. Obviously, the D/W ratio becomes higher as the gap width G reaches the narrow end of the acceptable gap width range. D/W = 0.8 is therefore the criteria that is use to determine the minimum gap width that can be welded without centerline cracking.

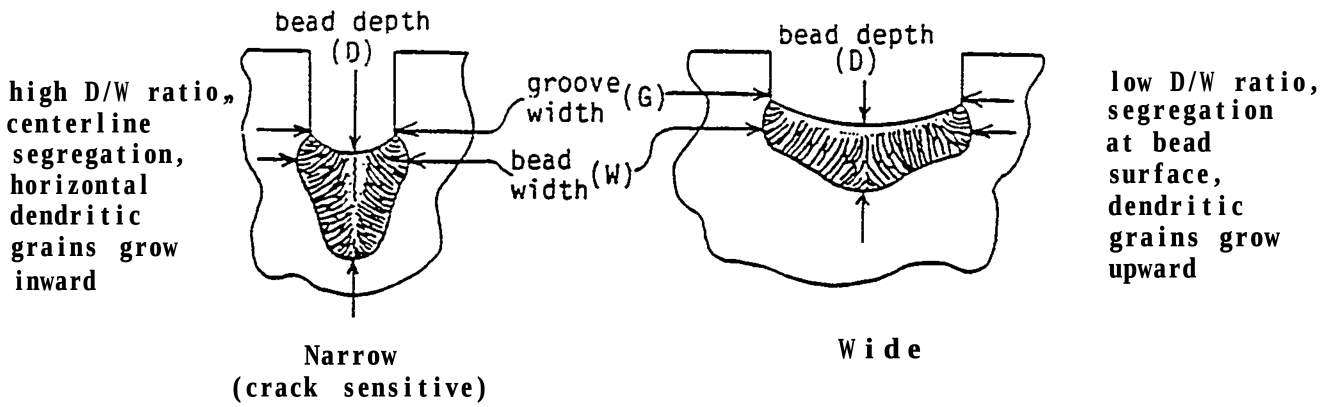


Figure 5. Depth/width ratio versus groove width

Testing has shown that the arc rotation mechanism described in Figure 1 works best at low current density for solid wire. If the amperage is raised too high, the two wires appear to produce a single steady arc and the weld cross section begins to take the shape of conventional GMAW. Figure 6 shows the penetrating spike that occurs when the arc becomes columnated and stiff at higher amperage. This increases the D/W ratio and thus the weld becomes more

crack sensitive. The bead *cross* sections outlined in Figure 6 are approximately to scale and were obtained with two twisted l/16" dia. (2 x L/16") solid electrodes and a gap width of 5/8". Although the 'maximum sidewall penetration W and the downward penetration D are increased with increasing amperage, the critical penetration W_I changes very little. The D/W ratio is drastically reduced at lower amperages, reducing the chance of solidification cracking. The lower amperage limit is reached when the arc becomes unstable. An unstable arc causes spatter which collects in the shielding gas hardware and blocks shielding gas flow. Excessive spatter will also collect on the *groove* walls and cause an undesireable bead surface as shown in Figure 3b.

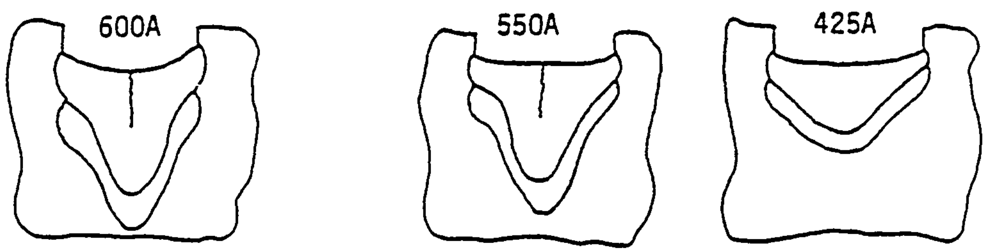


Figure 6. Depth/width ratio versus amperage.

Solidification cracking (D/W>0.8) can also occur when the travel speed is too fast. A slow travel speed increases the sidewall penetrations W and W_I much more than the increase in bead depth D. At faster travel speeds the sidewall penetration W decreases causing a higher D/W ratio and producing cracks at the narrow end of the gap range. At the same time a fast travel speed lowers sidewall penetration at W_I 'producing lack of fusion at wider weld gaps. For a given electrode size, optimum travel speeds and amperage ranges must be determined if weld joint root opening tolerances are to be successfully determined. The lower travel speed limit is reached when

either: 1) the weld puddle becomes so large that it rolls ahead of the arc and causes lack of fusion at the bottom of the weld bead; or 2) when the weld puddle becomes so hot that it excavates the sidewalls causing excessive undercut. An example of lack of fusion at the bottom of the bead, and undercut caused by slow travel speed is shown in 'Figure 7. Undercut is most often caused by the voltage being too high. Figure 7 shows how undercut leads to lack of fusion.

Figure 7. Undercut that causes lack of fusion

USEABILITY

One of the primary objectives of this study was to evaluate the useability of the twist wire process. Useability is defined as the ability to reliably produce high quality welds, with desired mechanical properties, over a wide range of gap widths, using a wide range of welding parameters even when the joint contains gouges or other local defects.

Because -of the configuration of narrow gap joints, repair of weld defects such as lack of fusion, undercut or porosity during welding is difficult due to the limited accessibility. Also, the repair may cause damage to the side

wall of the joint which will in turn lead to more defects during subsequent welding. Because of this accessibility problem, repairs during welding may eliminate the cost advantage of this process if they happen too frequently.

The useability must also be based on the ability of the final weldment to pass nondestructive testing with a low reject rate. As with other narrow gap welding methods, the biggest hurdles are lack of sidewall fusion, reasonable production weld joint fitup tolerances and weld parameter tolerances. Many previous narrow gap welding methods have failed to be useable because lack of sidewall fusion is obtained when: 1) tight weld joint fitup tolerances can not be met in production; 2) the welding parameter range is too restrictive to be realistically maintained; 3) the parameters must be changed during welding to allow for fluctuations in joint fitup; or 4) seam tracking tolerance requirements are too restrictive and cannot be met.

To evaluate useability, test plates as shown in Figure 8 were run at different amperage, voltage, travel speed, and stickout. The parameters were varied to determine allowable ranges for making sound welds (i.e., good sidewall, fusion, no centerline cracking, no undercut, and very little spatter). A summary of defect types and causes are shown in Table 1.

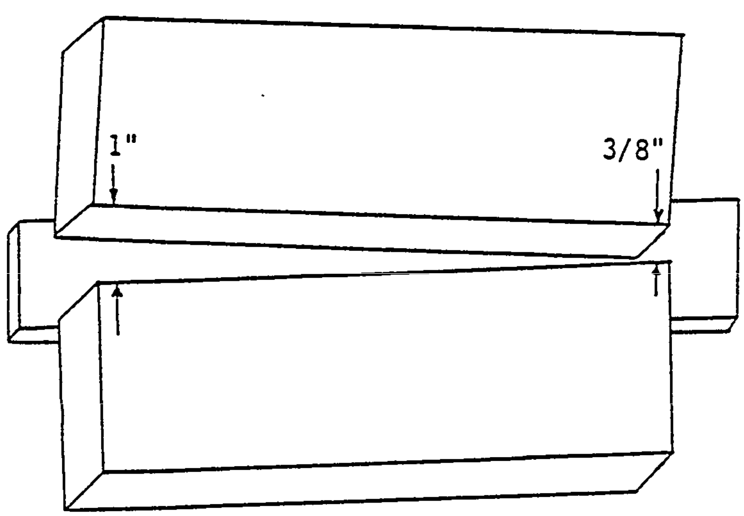


Figure 8. Schematic drawing of weld test plate.

Defect Type	Causes: Gap Width	Travel Speed	Amperage	Voltage	Stickout
SOLIDIFICATION CRACKING (Depth/ width >0.80)	too narrow (a)	too fast	too high		
LACK OF SIDEWALL FUSION at bottom of bead	too wide (b)	too fast			
LACK OF FUSION BETWEEN TWO WELD BEADS caused by an excessively large weld puddle rolling in front of the arc	too narrow	too fast	too high		
UNDERCUT (causing lack of fusion on the next pass)	too narrow	too slow		too high	
EXCESSIVE SPATTER, unstable arc			too low	too low	too short

(a) The depth-to-width ratio is labeled D/W on Charts I-IV. Freedom from solidification cracking was assured by D/W < 0.8. Charts I-IV show that D/W increases as the gap width G decreases, therefore D/W = 0.8 determines the minimum reliable gap width.

(b) The "lack of sidewall fusion at bottom of bead" factor is labeled W -G on Charts I-IV. Freedom from lack of sidewall fusion at bottom of bead was assured by W_1-G > 2/64". Charts I-IV show that W -G decreases as the gap width G increases, therefore WI-G = 2/64" determines the maximum reliable gap width

TABLE 1. Summary of defect types and causes

The results of useability tests with various electrode sizes (2x.049", 2x1/16", 2x2mm, 2x3/32") and electrode types (solid, and flux cored) are shown in Charts I through IV. Photographs of macro-etched bead cross sections using the various electrodes and parameters are included in Appendix 2.

D/W vs G (probability of solidification cracking versus gap width) and W_1-G vs G (sidewall penetration in the critical location versus gap width) were

chosen for comparison on each Chart I-IV because these factors will indicate the fitup tolerances. The chances of centerline cracking at narrow groove widths and probability of lack of fusion at wide groove widths define the total acceptable gap width range. For the sake of comparison a travel speed of 10 ipm was used in Charts I-IV. A travel speed of 10 ipm was within the optimum range *for* all electrodes tested. The voltages varied to correspond to the amperage ranges tested. The stickouts varied according to the optimum arc charateristics for each wire tested.

EQUIPMENT

Wire Twister

A machine capable *of* twisting weld quality electrode is essential for evaluating the twist wire welding process. The development of a successful wire twister has allowed the twisting of various sizes and types of electrode with major gains in the area of the flux cored twist wire development, and knowledge of the potential problems with wire quality.

Photo 1 shows the first wire twisting machine developed at Puget Sound Naval Shipyard. From this machine we learned that the twist wire must have the following properties to obtain quality welds:

a) 25 - 30 degree *twist* angle
b) wires must be twisted tightly together
c) wires must not be serrated or gouged
d) wires must be equally twisted around each other
e) must not have residual torque after it is spooled
f) must be properly level wound
g) must be straight

The second prototype wire twister shown in Photo 2 was developed with an emphasis on eliminating electrode helix. Normally, after the wire is twisted it is at residual yield point torsion. When the wire at yield point torsion is bent over the curved surfaces of the drive wheels or the wire take up spool it exceeds the yield point and is plastically eformed into a permanent helix.

The .045" diameter twist wire with helix will weave from side to side in the joint during welding causing lack of fusion when the wire wanders too far from the centerline of the joint. A wire straightener will not eliminate the helix problem with .045" diameter electrode since the wire is so flexible it can not be easily plastically straightened. However a wire straightener is effective on the larger diameter wires. Therefore, helix on larger diameter wire (2mm, 3/32") is not critical to the welding process.

The second wire twister eliminated helix by backspinning the take-up spool end of the wire so that it rotates in the grooves of the drive wheel. In this way the torque is relieved at the same time the wire is bent over the surface of the drive wheels. When the torque is lowered below the yield point, the added bending force over the drive wheels will not result in excessive plastic flow and a helix. For backspinning to be effective, the drive wheels must be large enough to transmit torque over the curved surface. The wire must be free to turn axially.

The backspinning also eliminates the residual torque in the as-spooled wire. Residual torque in the spooled wire produces a strong tendency for the wire to spring off the spool and tangle. Too much backspinning will cause reverse helix and may cause the wire to untwist. If the wire untwists a larger composite wire diameter is created which causes the wire to hang up in the contact tip resulting in an erratic arc and burn back.

The tension equalizer shown in Photo 3 attached to the end of the spinning arbor is an important part of the wire twisting machine. This device equalizes the feed rate of the two wires as they leave the arbor and are intertwisted.

Without the tension equalizer, a small differential change in the tension of the wires will cause them to twist unequally around each other. This

unequal twisting or looping, even when difficult to detect visually, will cause the electrode to hang up in the contact tip due to the increase in the combined twist wire diameter.

The tension equalizer shown in Photo 3 is made up of four wheels keyed together. When one wire is pulled from the arbor, torque is transferred to the other wheels. This forces the second wire to feed at the same rate, producing equal twisting.

Welding Equipment

The gas shielding device and the welding torch must be designed specifically for narrow gap twist wire welding. The remaining equipment is similar to conventional Gas Metal Arc Welding (GMAW) or Submerged Arc Welding (SAW) equipment. Currently, the only twist wire welding equipment available on the market is the TW-1 system made by Kobe Steel, the pioneer of twist wire welding. The TW-1 system is a well designed, complete equipment package that was made specifically for twist wire welding. A complete list of system components is included in Appendix 1.

Two special features of the TW-1 are a remote control adjustment for centering the electrode and an excellent shielding gas system. The centering device is a small remote hand held pendant on a four foot cable with two buttons to move the electrode left or right to center the electrode in the gap. Currently, the travel speed can not be adjusted during welding because a small turn of the knob will set the travel speed beyond the acceptable range. It would be beneficial to have a fine travel speed adjustment knob which could be turned at least 90 degrees to vary the travel speed smoothly within an acceptable range of set travel speed limits. The TW-1 shielding system is made up of two separate, interchangeable devices for different base metal thicknesses. For joint depths 2" to 11" a shielding gas nozzle is

attached to the torch so that the shielding gas ports are inside the groove. For weld passes 2" deep up to the cover pass the shielding *gas* nozzle is replaced by a shielding gas box which forces and floods shielding gas into the joint from above the plate surface.

CONCLUSIONS

Presently, Puget Sound Naval Shipyard's testing of the twist wire process has focused on detenining which types and sizes of twist wire are useable for narrow gap welding. The conclusions, based on the Charts I-IV, are summarized below:

a) 2x1/16" solid twist wire is unacceptable. The D/W ratio versus G curves of Chart I are too high and intersect the D/W=0.8 limit at a high gap width value. The sidewall penetration in the critical location WI-G versus gap width G curves of Chart I are low, thus intersecting the W_1-G=1/32" limit at a low value of G. Thus, the minimum gap width is too wide, the maximum gap width is too narrow, and the gap width range is not broad enough to allow for the fitup tolerances required in the shipbuilding industry. The useable gap width range is marginally acceptable at 425A;
however, the current density is too low at 425A for reliable *arc* stability.

b) 2x2mm solid twist wire provides a sufficiently broad gap width range between 500A and 550A. The D/W ratio is lowest at 500A, thus the gap width can be narrower and still avoid solidification cracking. Below 500A the arc becomes unstable. Above 550A the D/W ratio is too high to reliably produce a crack free weld pass over a sufficiently wide gap width range.

c) 2x1/16" flux cored twist wire is unacceptable. The sidewall penetration curves of Chart III are too low and intersect the WI-G=1/32" limit at a low gap width value. Thus the range of usable gap widths is not broad enough to allow the required +1/8" fitup tolerance believed to be necessary in

the shipbuilding industry. The D/W ratio versus gap width curve is acceptable over a broad amperage range of 350A to 550A. The low D/W ratios are typical of flux cored twist wire with arc stabilizers producting continuous arc rotation.

d) 2x3/32" flux cored twist wire has an' extremely wide range of useable gap widths, very high sidewall penetration curves, extremely low D/W ratio curves and a broad amperage range.

As a practical matter, the ideal joint width range is l/2" - 3/4". Below l/2" joint accessibility and visibility become more of a problem. Defects which occur in a groove less than l/2" wide are more difficult to remove than defects in grooves with wider gaps.

Table 2 below shows the values for D/W and W_1-G at l/8" intervals within the desireable gap width range of 1/2"-3/4".

		G range		D/W (0.8 max)			W_1-G (.03 min)		
	Amperage	min.	max.	G= 1/2"	G= 5/8"	G= 3/4"	G= 1/2"	G= 5/8"	G= 3/4"
2x2mm solid	500	.47	.83	.78	.63	.53	.07	.05	.04
	550	.56	.83	.88*	.75	.60	.07	.05	.04
	650	.68	.83	.97*	.85*	.74	.10	.08	.06
2x3/32" flux cored	550	.37	.86	.60	.48	.38	.14	.07	.03
	650	.37	1.	.62	.56	.50	.19	.15	.13

* D/W is unacceptable (see footnote a of Table 1).

Table 2. Comparison of the two useable twist wire electrodes

At this time in the test program it is known that the 2x2mm solid twist *wire is* suitable for production use and it appears that the 2x3/32" flux cored twist wire has additional advantages over the solid twist wire for narrow gap welding in the shipbuilding industry. It is important to note that much additional testing is required to determine the useability. Additional

useability tests should include tests to determine:

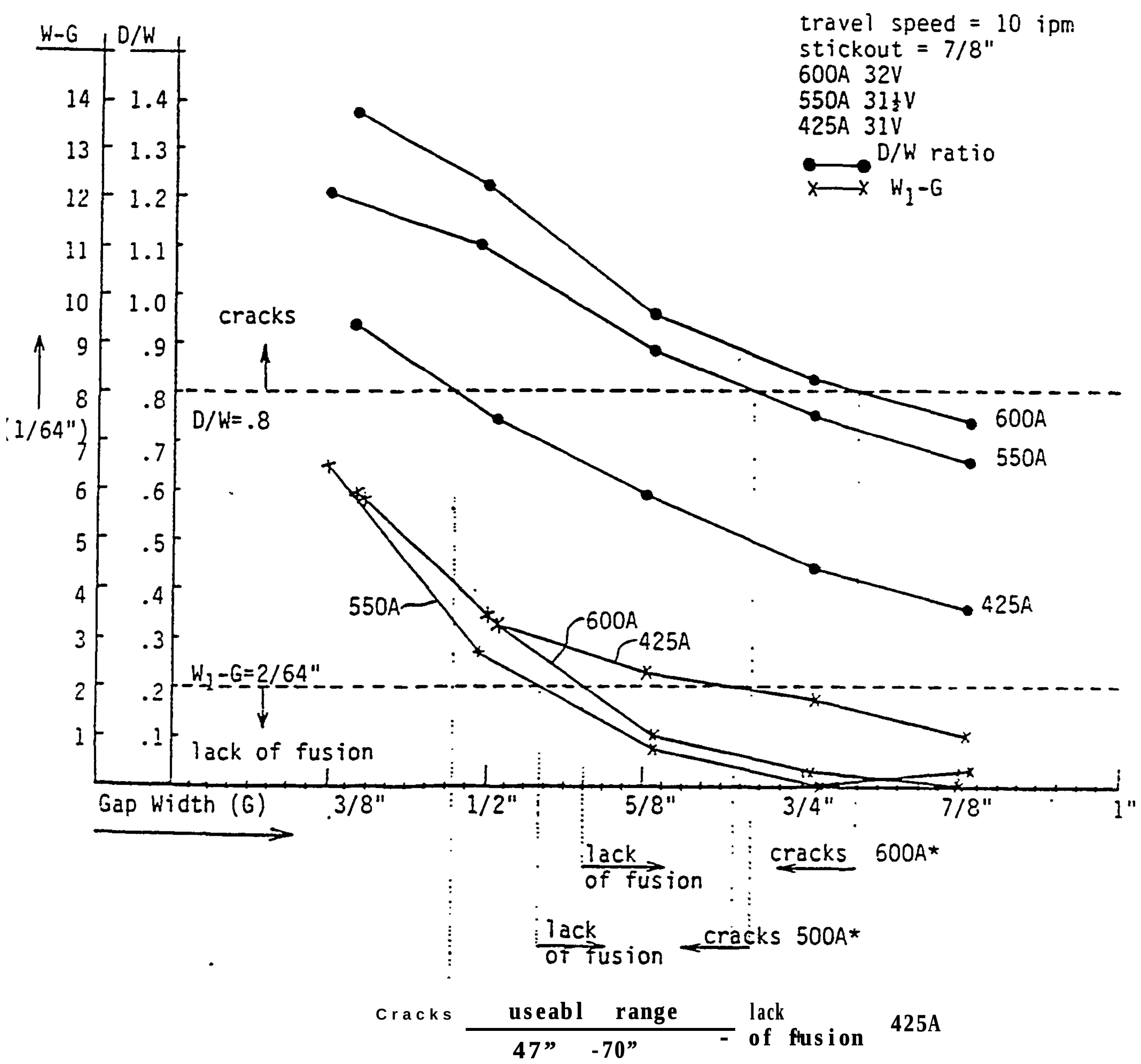
1) the electrode centering tolerance
2) the travel speed range
3) acceptable amperage, voltage, and travel speed combinations
4) contact tip life
5) sensitivity to defects in the sidewall
6) ability to repair surface defects by carbon arcing and grinding

LIST OF REFERENCES

1) Kimura, S., Ichihara, I., and Nagai, Y., "Narrow-Gap, Gas Metal Arc Welding Process in Flat Position", Welding Journal, July 1979, pages 44-52.

2) Yasuhiro, Nagai, Chigasaki; T. Osisada, Kashinura, Kamakura; Kunio, Kaita, Kamakura, & Tetsuro Kawaberi, Kamakura, all Japan; assigners to Kabushiki Kaisha Kobe Seiko Sho, Kobe, Japan; "Arc Welding Process Using a Consumable Stranded Wire Electrode ", United States Patent Publication No. 4,386,259, filed March 31, 1981.

2 X 1/16" SOLID ELECTRODE

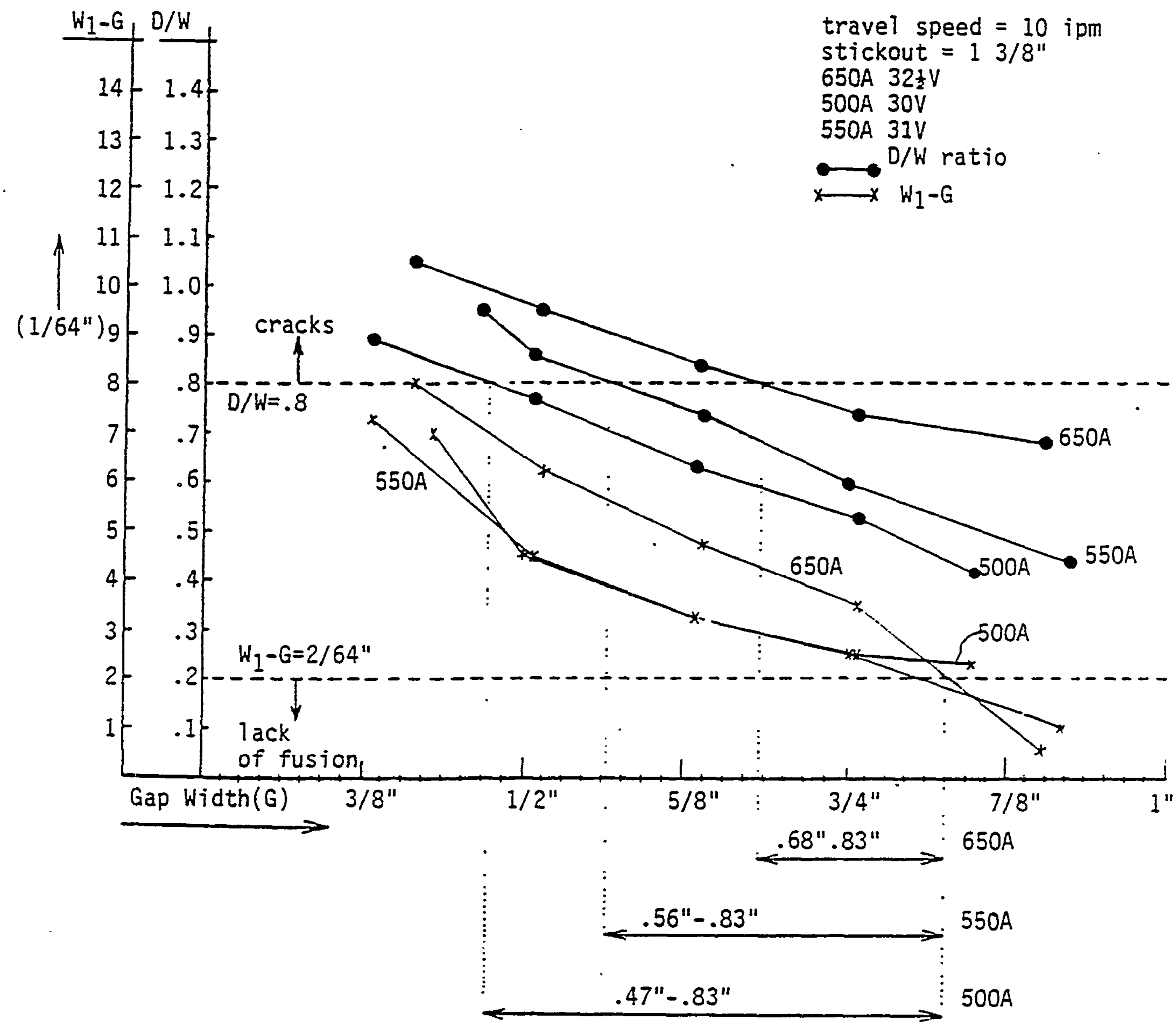


* No useable range at high amperage because of a high risk of cracks or lack of fusion at any value of G.

See footnotes a&b of Table 1.

Chart I

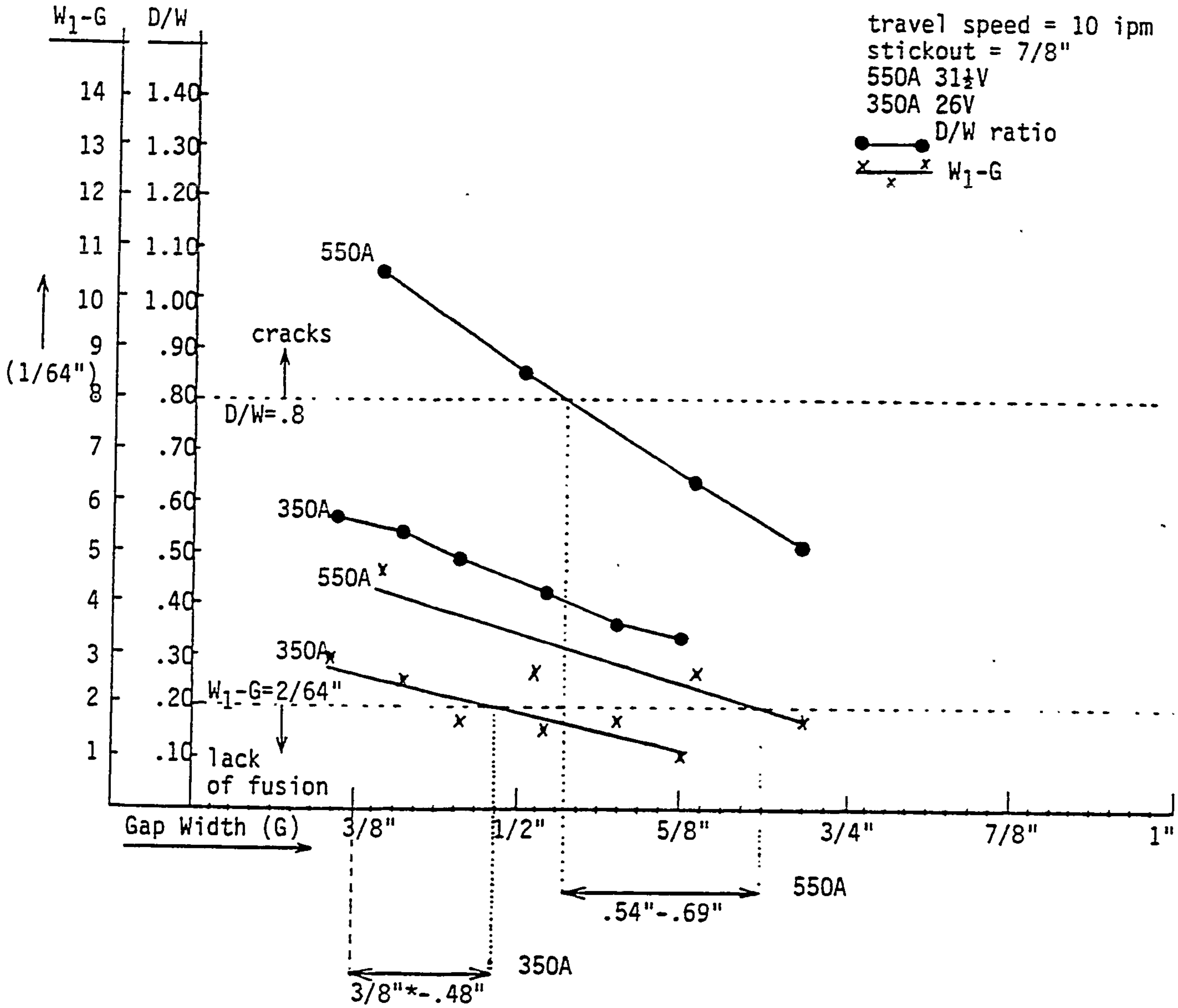
2 x 2mm SOLID ELECTRODE



See footnotes a&b of Table 1.

Chart II

2 x 1/16" FLUX CORED ELECTRODE

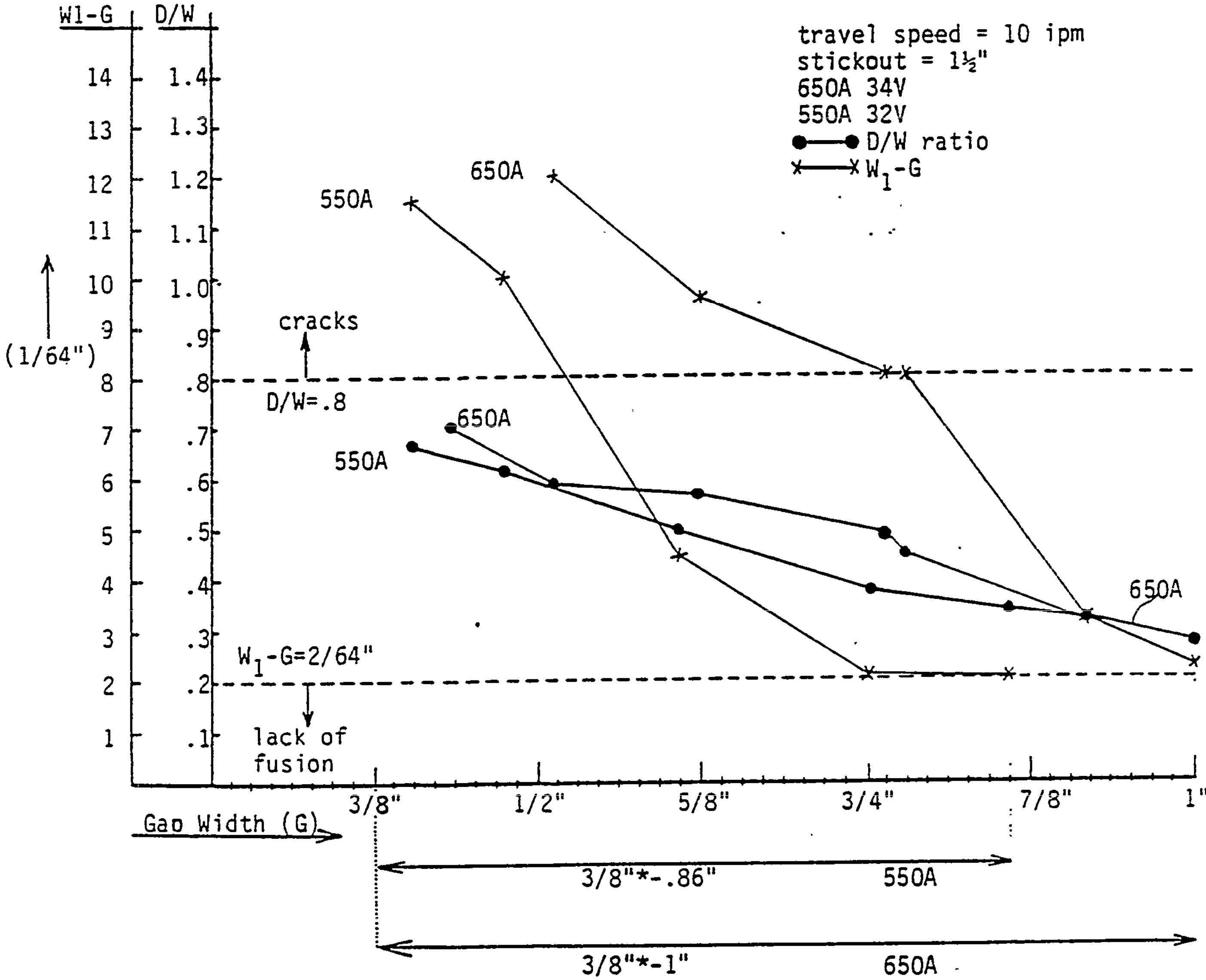


See footnotes a&b of Table 1.

*** The D/W ratio is so low with flux cored wires that the D/W ratio curves only intersect the D/W=0.8 limit at high amperage. At low Amperage the lower gap width limit is set at 3/8". Below 3/8" the gap width is too narrow to accomodate the contact tip.**

Chart III

2 x 3/32" FLUX CORED ELECTRODE



See footnote b of Table 1 for explanation of upper limit.

*** The D/W ratio is so low with flux cored wires that the D/W ratio curves do not intersect the D/W=.8 limit. The lower limit is set at 3/8". Below 3/8" the gap width is too narrow to accomodate the contact tip.**

Chart IV

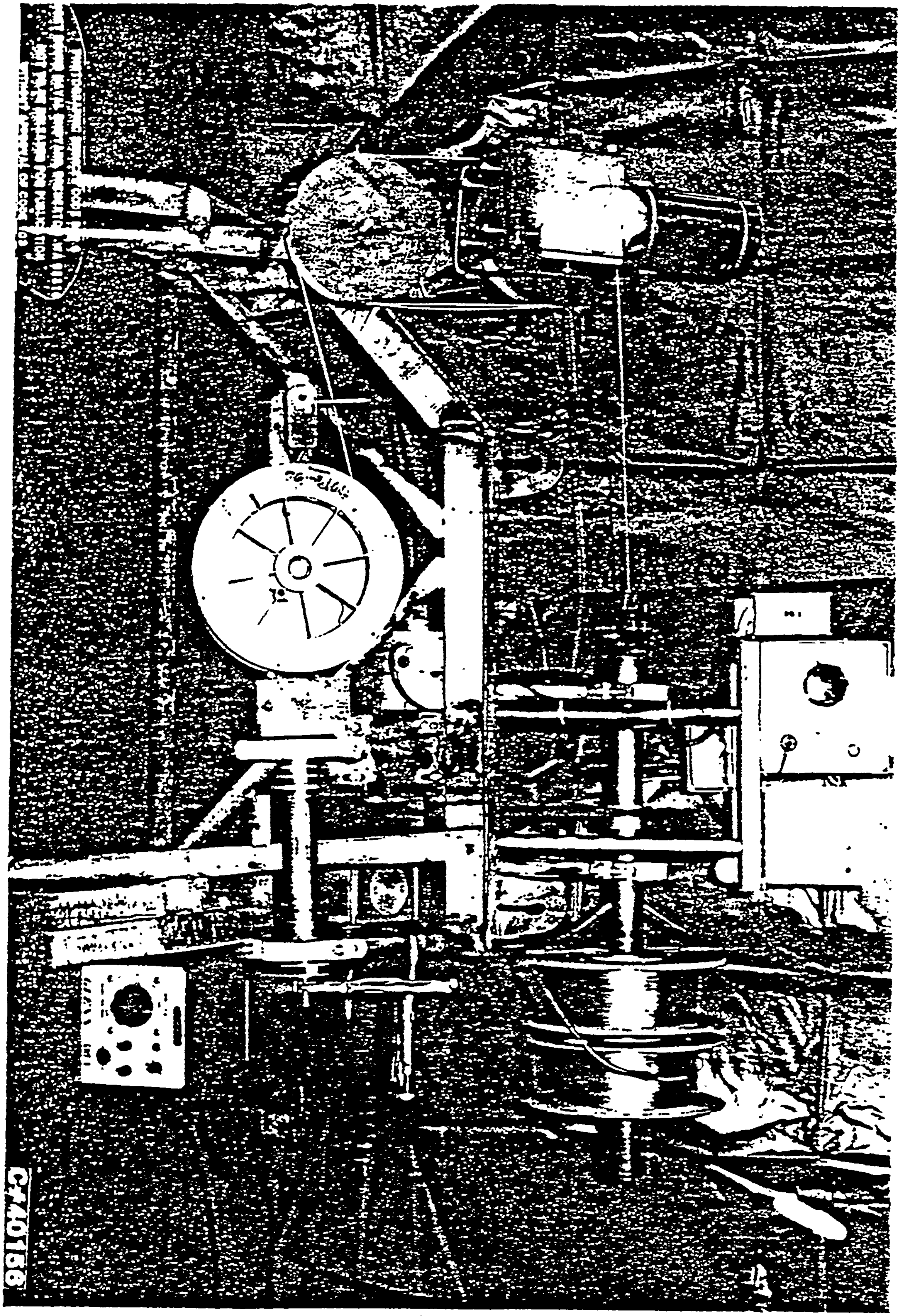


Photo 1

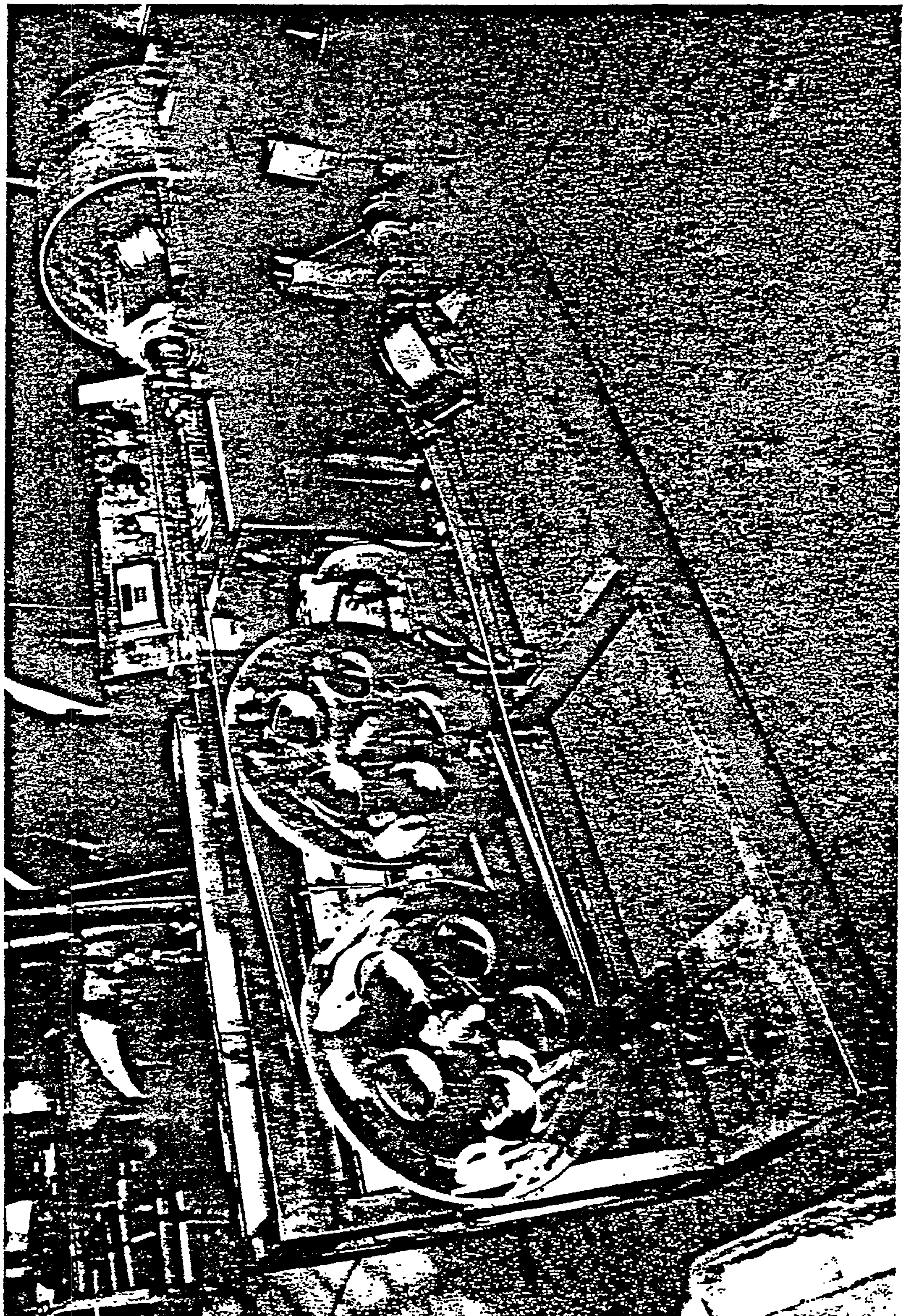


Photo 2

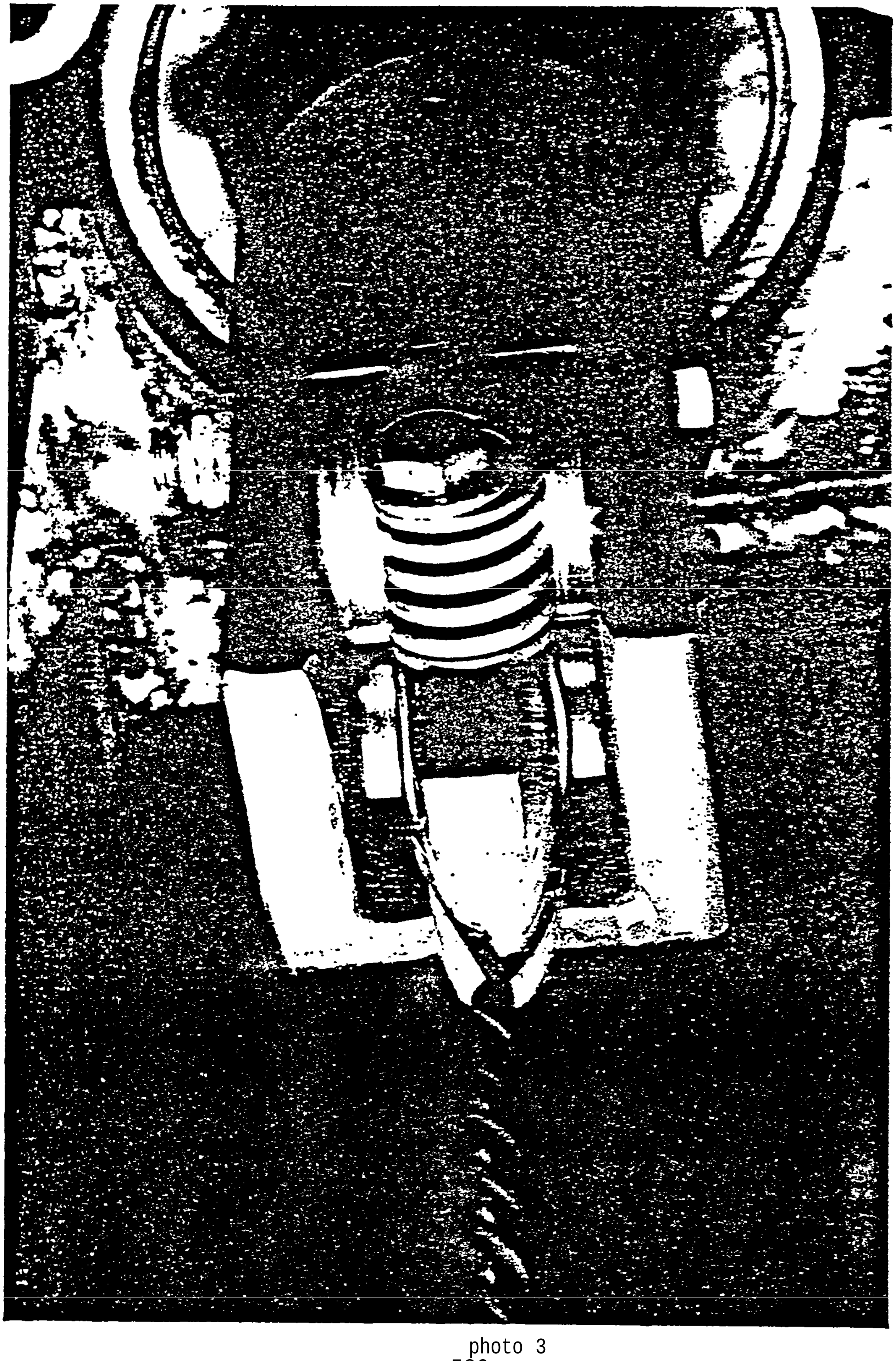
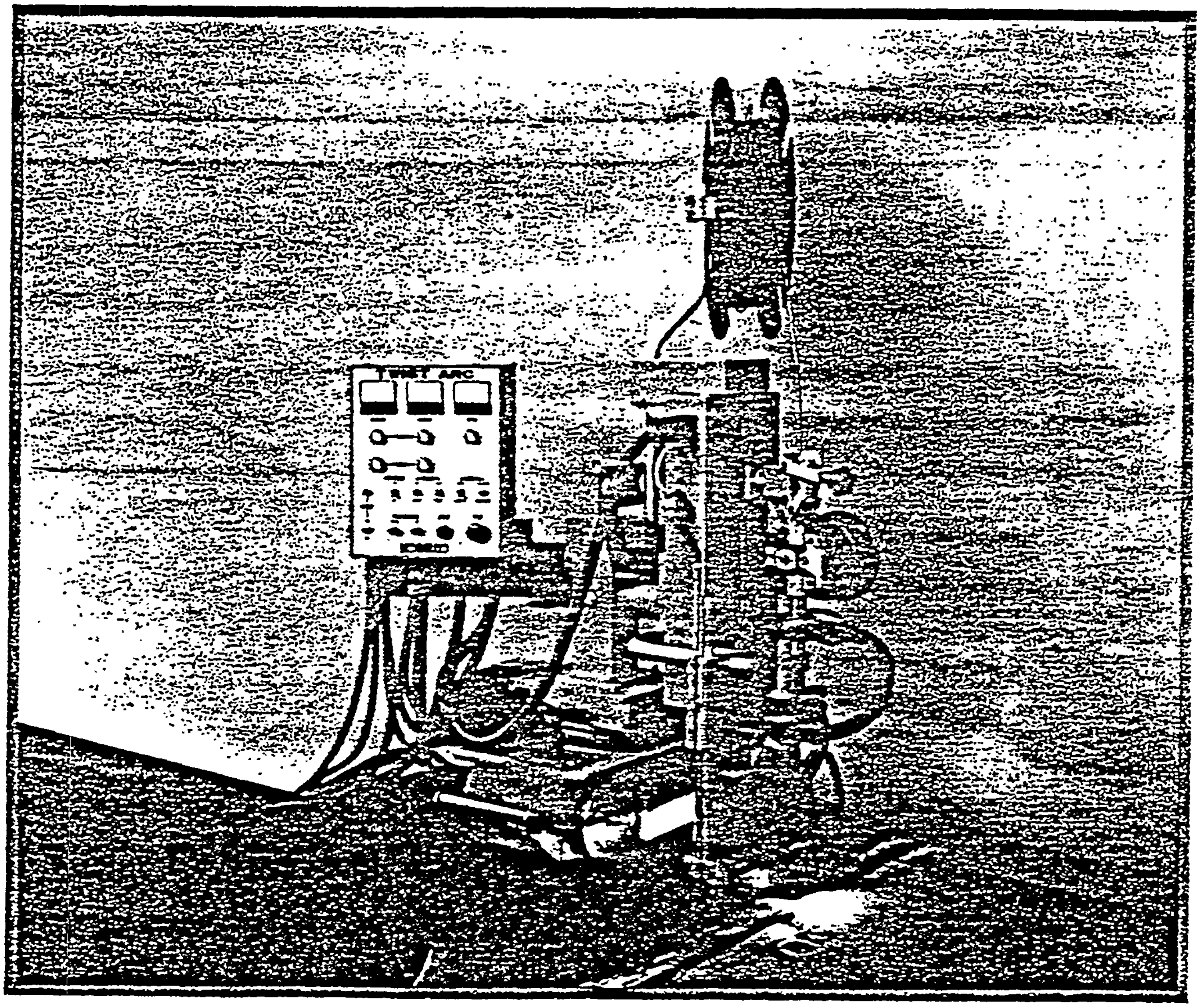


photo 3

TW-1

TWIST ARC WELDING EQUIPMENT

Narrow Gap Gas Shield Arc Welding Equipment



KOBELCO

KOBE STEEL, LTD.
WELDING DIVISION

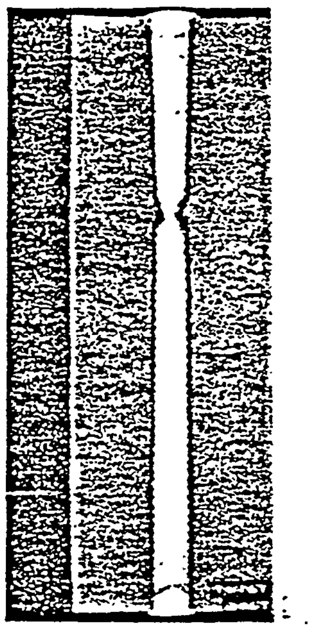
TW-1

TWIST ARC Welding Equipment "T W - 1 " demonstrates the best reliability and economy in the TWIST ARC welding process.

Features

o Easy operating welding equipment because of its simples structure.

For conventional narrow gap welding equipment. it is necessary to bend the wire and to have oscillation in order to penetrate a narrow gap wall. But, with this equipment using a special wire of two threaded wires. such a function is not required and by simply feeding the wire into the center of the narrow gap, narrow gap welding can be performed at a high reliability.



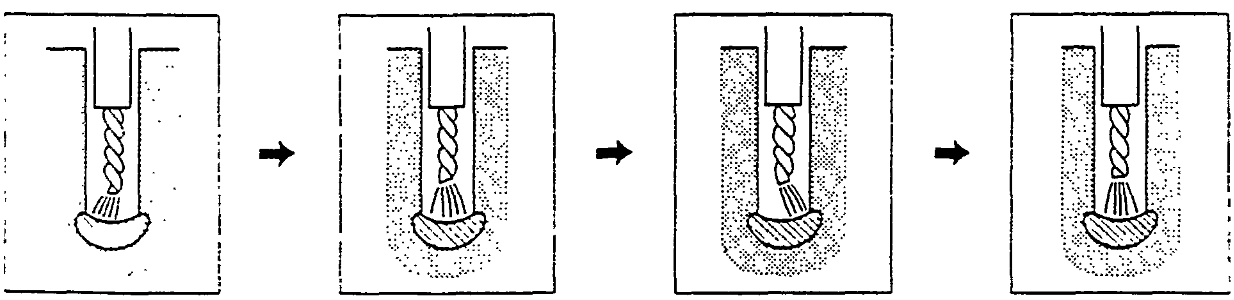
G Up to 300mm thick welding is available because the location of the long stroke torch can be adjusted up and down.

c Torch location can easily be adjusted in the narrow gap with just observing the are by a remote pendant box which can be held in one hand.

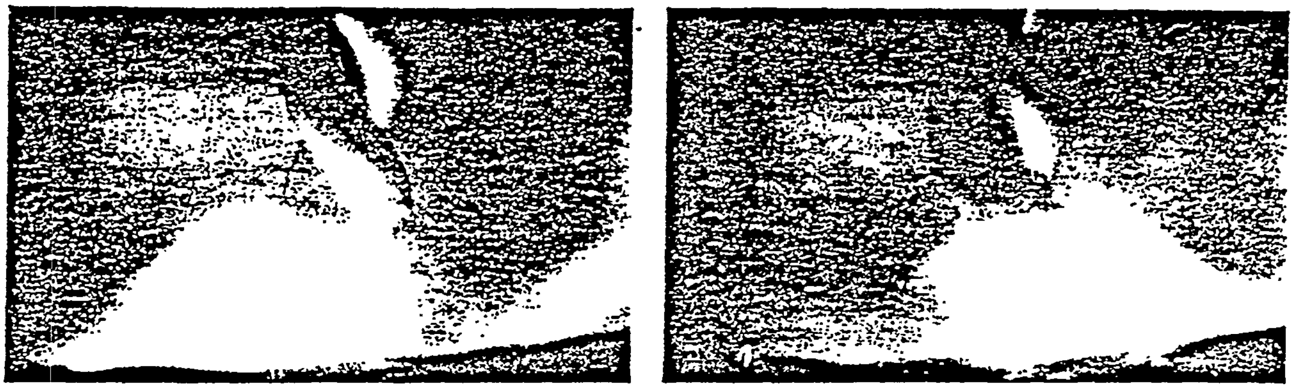
.f Being removable from the travel carriage. the welding head of TW-1 can be easily mounted on the manipulator.

TWIST ARC Welding Method means

This IS a method which naturally causes swing and rotation movement of the welding arc generated from the ends of two intertwined wires. this assuring sufficient penetration into the narrow gap wall. assurmg attainment of concaved bead surface shape and preventing blow holes inherently occuring in MIG welding. because of the effects of active convection and mixture of molten metal characteristic of the above-mentioned movement.



Swing and rotation of welding arc



Generating status of welding are
(as show by htgh-speed film)

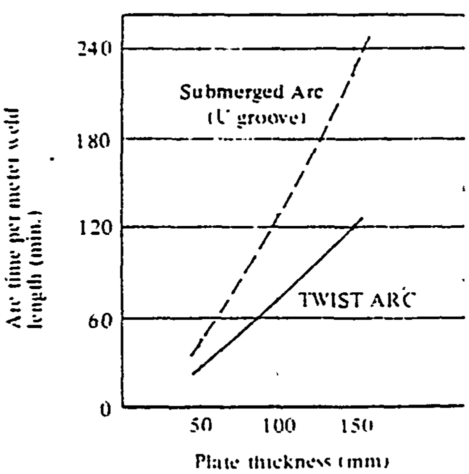
Features of the TWIST ARC Welding Method

- Highly Efficient and Economical

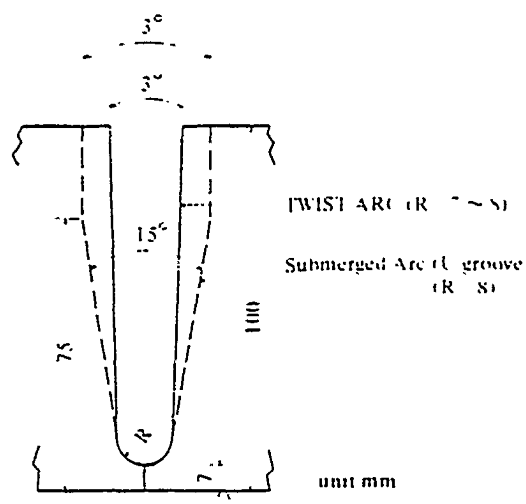
Because the cross-section of a gap welded by the TWIST ARC is smaller than that welded by Submerged Arc, this method is economical as well as highly efficient.

- High Reilability with : Simple Operation

Because of the above mentioned features of TWIST wire, sufficient penetration into the narrow gap wall easily be obtained, and by roughly adiusting the wire feeded point to the center of the narrow gap, highly reliable welding can be performed.



A comparison of welding arc time



An example of narrow gap shape

Appendix 1

Application

- Applicable position : Flat position
- Applicable plate thickness : Max. 300 mm
- o Applicable material : Mild steel - 80 kg/mm’ class high tensile steel, low-alloy steel for boiler and pressure vessel application
- o Groove width : 14^{+4}_{-2} π mm (I, J and U form)
- o Applicable joints : Circumferential and longitudinal butt joints for boiler and pressure vessel.

  Butt joints of thick plate for hydraulic power generator. heavy machinery. etc.

Typical Welding Conditions

- Welding current : 500 ~ 550A
- Welding voltage : 29 ~ 32V
- Welding speed : 20 ~ 40 cm/min.
- Shield gas : 80% Ar + 20% CO_2

  For shield gas nozzle

  Primary gas 5 ~ 10 min

  Secondary gas 50 . min

  For shield gas box

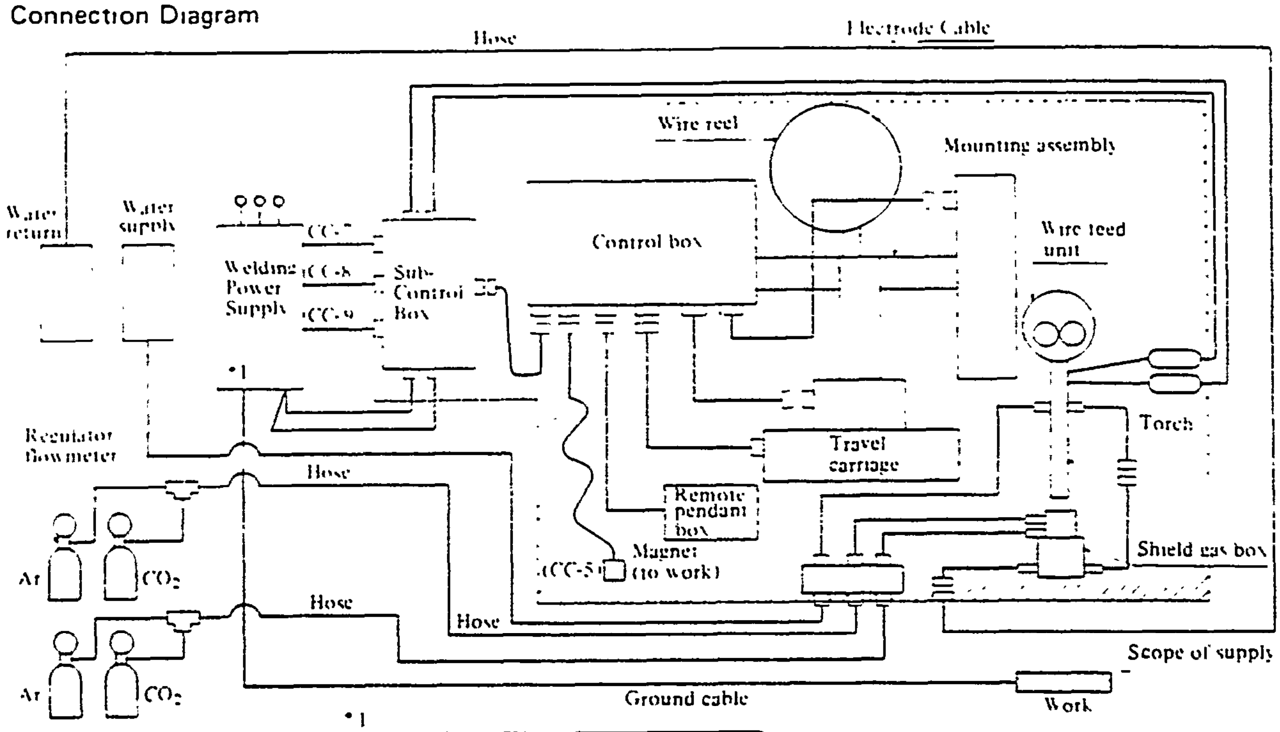
  Primary gas 50 ~ 60 . min

  Secondary gas 50 ~ 60 ./min.

Components and Specifications

Components		Specifications
Travel Carriage	Travelling. method	Rail guide friction method
	Travel speed	I .S - 85 cm/mm. 15.9 - 33.5 mch/min).
	Clutch	A manual clutch
	Dimensions and weight	330W x 760D x 17SH mm 39Kgt (13.OW.x 29.9D x 6.9H inch, 86 lbs)
Mounting Assembly)	i Cross-steam adjustment	Stroke: 80mm (3.2 inch) electric tnching method Slide speed: 12/14 cm/min. (4.7/5.5 inch/min) (50/60 Hz)
	Vertical Head adjustment	Stroke: 350mm (I 3.8 inch) electric inching method Slide speed: 24/28 cm/mm. 19.4/II inch/min.) (50/60 HZ)
	Torch angle adjustment	±110°(to the level) by manual hand knob
	Dimenstons and weight	57OW x 300D x 7OOH mm. 75Kgt (22.4W x II 8D x 27.6H Inch. 165 lbs)
Wire Feed Unit	Wire feed speed	Max 6 m/min it 9.7 it/min.)
	Applicabel wire size	2.0 x 2.0 mm (0.079 x 0.079 Inch)
	Dimensions and weight	26OW x 280D x 500H mm. 10kgf (10.2wx11.odx 19 .7H inch 22 lbs)
Shield Gas Box and Vertical slide	Shield gas box	Dual shilding. water cooled type
	Vertical slide	by manual hand knob
	Weight	6 kgf (13.2lbs)
Shield Gas Nozzle	Shield gas nozzle	Dual Shielding. water cooled type
	Weight	4 kgf (8.8 lbs)
Torch	Applicable wire size	2.0 x 2.00 mm (0.079 x 0.079 o Inch)
	Weight	2 Kgf (4.4lbs)
Tip	Applicable wire size	2.0 r 2.00 mm (0.079.007 inch)
Wire Reel	Applicable wire weight	20 kgf (44lbs)
	Dimensions and weight	500φ x 240D mm 9 Kgt (19.7φ x 9.4Dinch, 19.8 lbs)
Control Box	Controlling items	° Weld start ° Weld stop ° Welding current rheostat (with meter) ° Welding voltage rheostat (with meter) ° Travel speed rheostat (with meter) ° Gas test ° Wire inching (up/down) ° Cross-steam adjustment inching ° Vertical head adjustment inching ° Travel (forward/backward) ° Travel (automatic/manual) ° Crater current rheostat ° Crater Voltage rheostat
	Dimensions and weight	310W x 220D x 520H mm. 28 Kgt (12.2W x 8.7D x 20.5H inch, 61.7 lbs)
Remote Pendant Box	Controlling item	Cross-seam adjustment inching
Cables	Control cable	Welding power supply-Control box 20 m (65.6 ft)
	Electrode cables	80 mm² x 1 m x 2 pcs (with cable connectors) (0.12 inch², x 4.3 ft)
	Arc voltage detection cable	10 m (with a permanent magnet) (32.8 ft)
Sub-control Box\	Controlling items	Control power source ON/OFF Control power source indication lamp
	Dimensions and weight	300W x 400D x 210H mm. 20Kgt (11.8W x 15.7D x 8.3H inch, 44 lbs)
	Note: Characteristic of D.C welding power supply and specification of output control rheostat should be noticed in advance	
Rull	Dimensions and weight	250W x 1,800L x 60H mm. 30 Kgt (9.8W x 70.9L x 2.4H inch, 66 lbs)

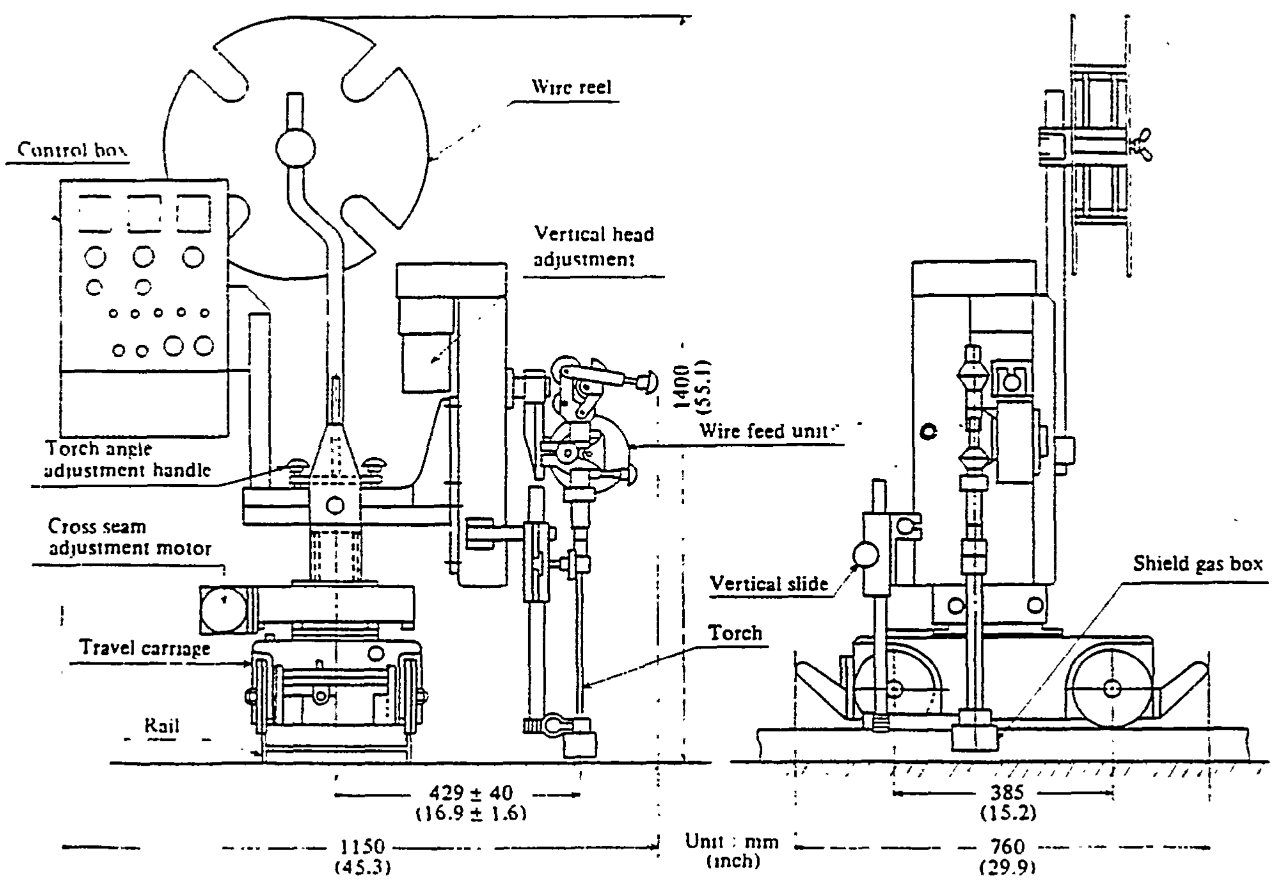
Connection Diagram



*1

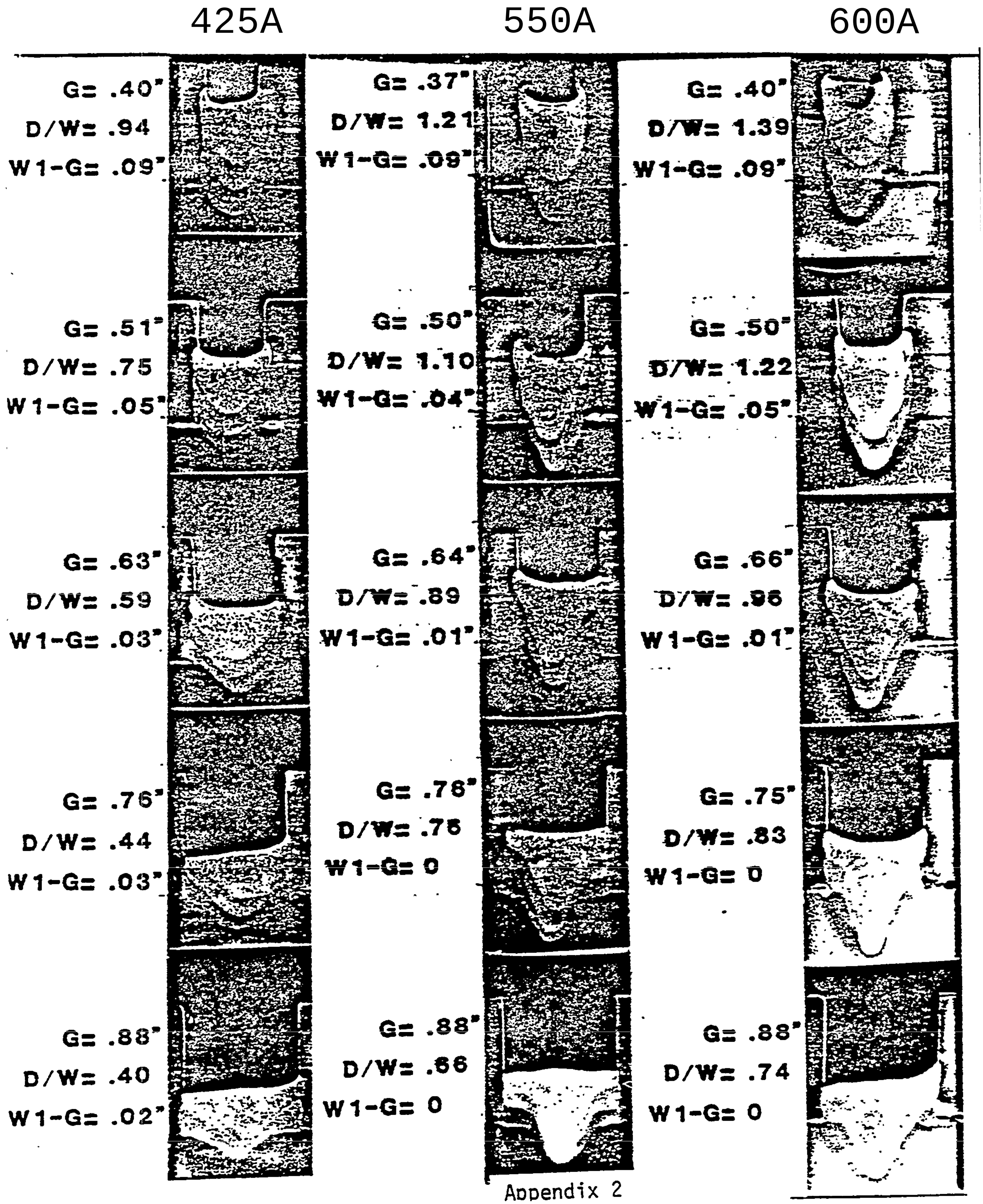
	Specification
Type	SCR output controlled three phase D.C. power supply
Characteristic	Dropping/constant voltage Characteristic should be noticed in advance.
Capability	Above 550 Amperes 34 Volts 100% duty cycle

General Drawing



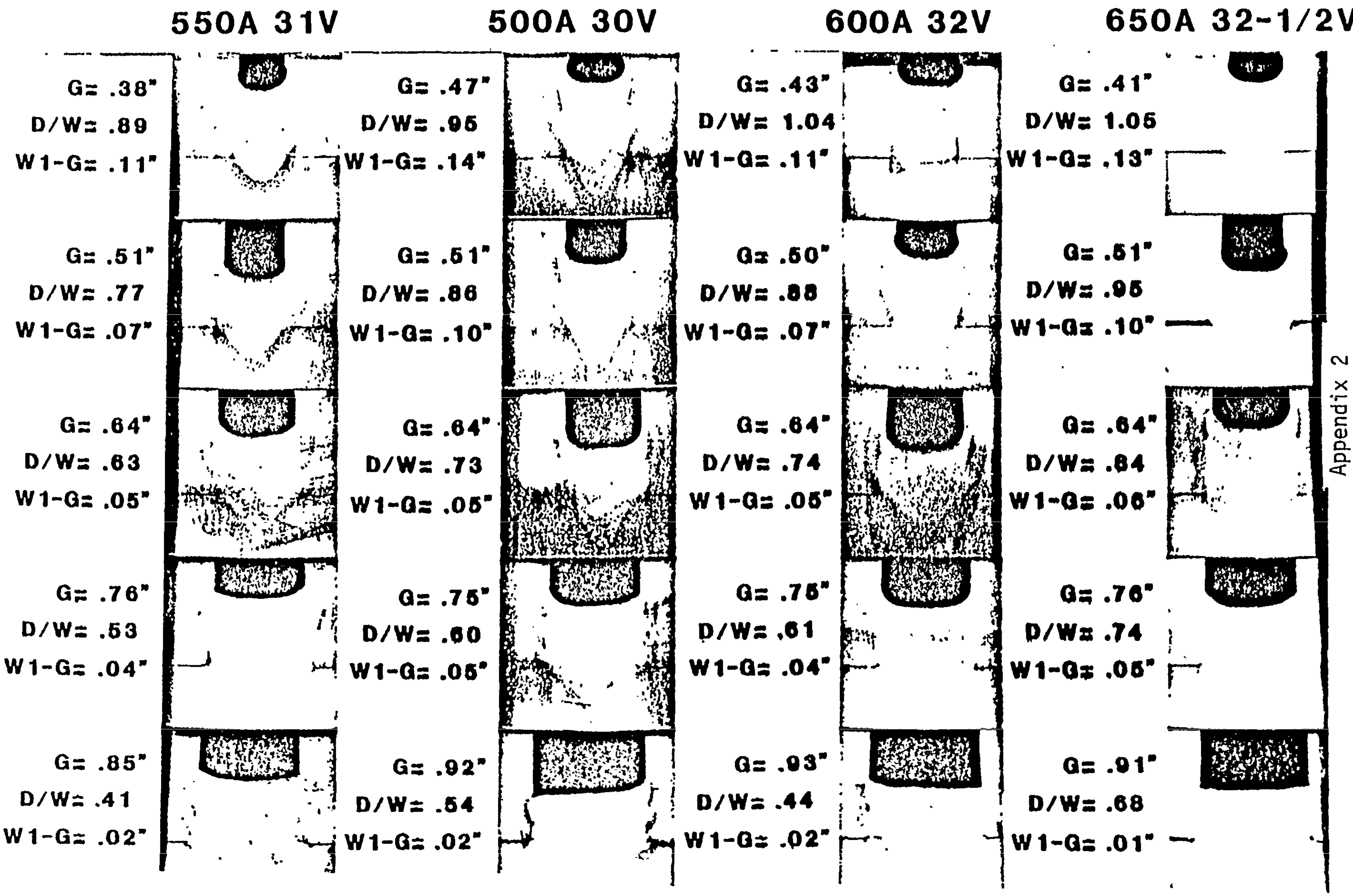
Appendix 1
Sheet 6 of 6

Twisted 1/16" Diameter Solid Wire Electrode



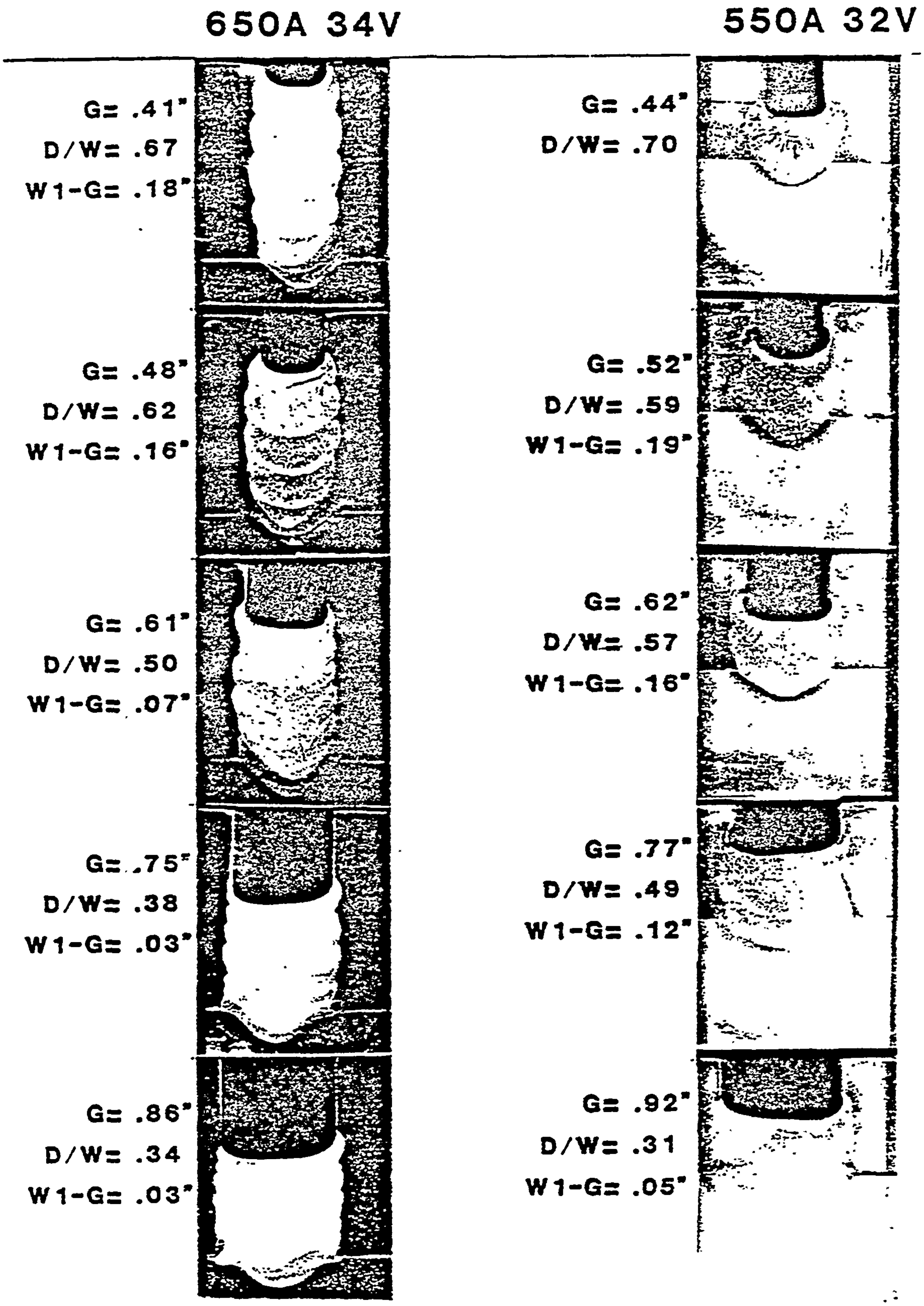
Appendix 2
Sheet 1 of 3

Twisted 2mm Diameter Solid Electrode



Appendix 2
Sheet 2 of 3

Twisted 3/32” Diameter Flux Cored Electrode



Appendix 2
Sheet 3 of 3

EVALUATE THE BENEFIT OF NEW HIGHER-STRENGTH HSLA (HIGH STRENGTH, LOW ALLOY) STEELS

PREPARED FOR

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1985 SHIP PRODUCTION SYMPOSIUM

LONG BEACH, CALIFORNIA

SEPTEMBER 11-13, 1985

PREPARED BY

J. C. WEST

BETHLEHEM STEEL CORPORATICN

BEAUMONT, TEXAS

EVALUATE THE BENEFIT OF NEW HIGHER-STRENGTH HSLA STEELS

As the continuing search for offshore oil heads toward deeper water, the need for sturdier designs and stronger steels multiplies. Thus the costs to build mobile drilling units and fixed platforms rise exponentially.

Steels with 50, 60, 65, 75, 80, and 100 ksi (thousand pounds per square inch) yield points in both the HSLA normalized and C-Mn-Si (Carbon-Manganese-Silicon) quenched and tempered conditions are available from various producers. Most of these steels above l-1/2 inches in thickness must be welded to themselves or other steels by using sustained preheat and controlled interpass temperatures, plus controlled welding heat input of approximately 50 to 60 KJ/inch (kilo joules per inch). These two items will add as much as 50 percent to the cost of welding when using the submerged-arc process. Cost increases up to 30 percent can be expected when stick welding under these conditions. The practice of using hand-held oxy-gas torches, by the welder, to drive out moisture or raise the steel above freezing conditions is considered as normal, with its cost usually included in the standard welding costs.

In our design improvement and cost reduction efforts, we found a steel capable of being welded without sustained preheat or limited heat input. This quenched and precipitation hardened steel is ASTM A710 Grade A Class 3. Due to its high degree of weldability, it shows great potential

for sizeable savings in welding costs. The use of HSLA-80, which is an 80,000 yield point material and a derivative of this specification, on Navy ships has been documented by SP-7 panel member L. G. Kvidahl of Ingalls Shipbuilding on page 42 of the July, 1985, issue of the "Welding Journal." This product has also been known in the trade as Armco's "NI-COP."

We proposed, through SP-7, to MARAD that a study, entitled as above, be conducted to fully explore the potential of this product. Work commenced in August, 1984, to accomplish the following goals:

Phase	Goal - Expected and Proven Results	Estimated cost	Scheduled Time
1A	80 ksi Y.P. through 3" thick	$ 95,000	1 year
1B	75 ksi Y.P. through 5" 'thick 70 ksi Y.P. through 6" thick	$ 75,000	9 months
2	100 ksi Y.P. through 3" thick	$ 70,000	6 months
3	90 ksi Y.P. through 5" thick 85 ksi Y.P. through 6" thick	$100,000	1 year
4	Publish results and develop market for proven products	$ 50,000	9 months
TOTALS		$390,000	4 years

As of mid-September we have finished our first year's effort. During this time we have welded 24 test plates, 20 of which have been tested.

The processes used were manual, gas metal-arc with pulse, and submerged arc (single, dual arc, and narrow gap). Heat inputs varied from 50 KJ/inch to 200 KJ/inch. Some plates were welded in the quenched only condition, and precipitation hardened after welding, others vice versa. Test results obtained thus far show a minimum yield of 84.7 ksi welded at 200 KJ/inch with dual arc to 97.6 ksi welded at 100 KJ/inch with the same process. Charpy "Vee" notch values were well above the American Bureau of Shipping values for EQ56 plates.

Some repair work and testing remains to be done to completely attain our Phase 1A goal. However, our initial findings indicate that heat input limitations on this material may not be necessary and the practice of good welding techniques is mandatory. We will continue to explore heat input limitations in our next phase of effort.

At the present time, this HSLA steel costs approximately 45 to 50 percent more than high strength C-Mn-Si quenched and tempered plates at the 50, 60, and 75 yield point ksi level. Potential cost reductions in welding labor costs of 40 percent to 75 percent are probable. This is due to being able to specify and use thinner sections of steel, requiring less volume of weld metal, that can be welded without preheat at very high heat inputs. These labor savings will far exceed the extra material costs by very wide margins.

An evaluation covering the above factors will be presented at the completion of Phase 1B before performing any work on 100 ksi yield point material. In addition, we will present other benefits to be gained by the use of this material. Some may be intangible and difficult to assess. These include:

1. The use of lighter material decreases the deadweight of the unit, thereby increasing its payload on reducing the power requirements to propel it.

2. Lighter material increases the length or width of plates ordered from the mill. This in turn reduces the number of butts on seams required in the unit's design. Therefore, welding requirements are further reduced.

3. Thinner higher-strength plates of greater surface area to construct a unit will reduce plate handling times at the site. Incoming freight bills will decrease as less tonnage is delivered to the carrier.

4. Less time and effort will be expended by architects and designers in producing the most economical product.

Definition of Terms

HSLA - high strength, low alloy

ksi - thousand pounds per square inch

C-Mn-Si - Carbon-Manganese-Silicon

KJ - kilo joules

Y.P. - yield point

MARAD RESEARCH PROJECT

HIGHER STRENGTH STEELS SPECIALLY PROCESSED FOR HIGH HEAT INPUT WELDING

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FOREWORD

This report presents the results of a research and development project initiated by the Ship Production Committee of the Society of Naval Architects and Marine Engineers and financed through a cost sharing contract between the U.S. Maritime Administration, Newport News Shipbuilding and Drydock Corporation and the American Bureau of Shipping. The principal objective was to identify steels used for hull construction that are resistant to heat affected zone degradation when welded with high heat input welding processes.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee who served as technical advisors in the preparation of' inquiries and evaluation of subcontract proposals; to Mr. B.C. Howser, Newport News Shipbuilding, SP-7 Panel Chairman and to Mr. M.I. Tanner, Newport News Shipbuilding, SP-7 Program Manager.

The program was carried out by the American Bureau of Shipping under the direction of Mr. I.L. Stern; Mr. M. Wheatcroft was the Project Manager; Dr. D.Y. Ku served as the Project Engineer and Mr. R.F. Waite supervised the laboratory testing.

In addition, the services of Avondale Shipyard; New Orleans, Louisiana in preparing the test weldments, the U.S. Naval Ordnance Station; Manufacturing Technology Department, Louisville, Kentucky in conducting the explosion bulge tests and the Nippon Steel Corporation and Kawasaki Steel Corporation who supplied the base metals are acknowledged.

EXECUTIVE SUMMARY

ABS Grade EH36 steel plates, specially formulated and produced with advanced metallurgical techniques are shown to have a significantly greater resistance to weld heat affected zone (HAZ) degradation than conventional EH36 steel. Welds made in these steels with the electroslag welding process at high heat input rates retained adequate toughness in the heat affected zone at -40F (-2O$^{\circ}$C); similar welds in conventional EH36 steel plate exhibit excessive HAZ toughness loss. The above was confirmed on the basis of small scale Charpy V-notch and large scale explosion bulge testing. In view of their superior resistance to HAZ degradation, the steels should also be useful for applications where HAZ degradation is of particular concern, such as for ABS, Coast Guard and International Maritime Organization (IMO) weld requirements for Liquefied Gas Carriers.

1.0 Background

A previous project, ‘Toughness Evaluation of Electrogas and Electroslag Weldments,” was completed by ABS under a welding research project sponsored by MARAD and ABS (Ref. 7). In this project the properties of welds in ABS ordinary and higher strength hull structural steels made-with the electrogas (EG) and electroslag(ES) high heat input welding processes were compared with those from the shielded metal arc (SMAW) and submerged arc (SAW) welding processes with a view toward extending the applicability of the high heat input processes in shipbuilding. Comparisons were made with respect to toughness, as evaluated by Charpy V-notch (CVN), explosion bulge, drop weight and dynamic tear tests. Several general conclusions regarding the applicability of the welding processes to the ordinary and higher strength hull steels were drawn; one conclusion was that the principal impediment to extending the application of ES and EG welding to ABS Grade EH36 is low toughness properties in the HAZ

A fundamental solution to the problem is to utilize steels metallurgically designed to retain adequate toughness in the HAZ. Such steels could also be advantageous for all welding processes in low temperature applications where HAZ toughness requirements are imposed.

2.0 Objective

The principal objective was to determine the suitability of specially treated and processed ABS Grade EH36 steels for welding with high heat input welding processes.

3.0 Achievement

The project has demonstrated the suitability of versions of ABS Grade EH36 steel plate which are specially suited for marine applications where resistance to HAZ degradation is of concern. Use of these steels should provide for welding of EH36 steel with the high deposition rate welding processes such as electroslag. These new steels should also be advantageous in applications such as low temperature service for carriage of liquefied gases, wherein minimum HAZ Charpy V-notch values are specified.

4.0 Approach

High toughness steels which are designed to retain significant toughness levels in the HAZ of welds have been recently developed. The approach in this project was to select candidate steels and weld these steels with ES welding processes which utilize exceptionally high heat input rates. Weldments in these steels were then evaluated by examining the results of small scale CVN impact tests of the HAZ, and of large scale explosion bulge tests to substantiate the CVN toughness indications. Results were compared with ES, SAW and MMA weldments obtained from a previous investigation of conventional normalized ABS EH36 steel (Reference 7).

5.0 Base Material Selection

Based on a literature search (1-4) and the availability of steel, the candidate steels selected were:

a. Ti-treated steel.

b. Ti-B-treated steel.

c. Ti-REM-B-V-treated steel (Note: REM = Rare Earth Metal).'

The features common to these steels which distinguished them from the reference conventional EH36 steel were: extremely low sulfur levels, low carbon equivalents, fine ferrite grain size and intentionally added titanium. In addition, all had been produced with advanced metallurgical techniques (Thermomechanical Control Processing and Thermomechanical Control Rolling).

Chemical composition and mechanical properties of base materials are shown in Tables 1 & 2. A discussion on the metallurgical characteristics of these steels is in the Appendix.

6.0 Weldment Preparation

The ES welds were made with a heat input rate of 480 KJ/in. at a shipyard. This heat input, which is toward the low end of the range typically used in ES welding, was used because available filler metals will not meet ABS required - CVN values for EH36 when deposited with heat inputs of the order of 1000 KJ/in. Table 3 indicates the welding conditions and plate thicknesses.

Consumable nozzle electroslag (CES) weidments submitted by one of the manufacturers of the candidate steels were also evaluated. The steels, Ti-treated and Ti-B-treated were CES welded with the welding conditions shown in Table 4; heat inputs were 1252 KJ/in and 1146 KJ/in respectively.

Table 5 indicates the chemical composition of the electrodes used in ES and CES welding.

7.0 Testing Procedure

7.1 Mechanical Testing and Examination of Base Materials

The following testing was conducted for each base plate:

a) Longitudinal Tensile Tests (0.50 inch diameter specimen with 2 inch gauge length).

b) Longitudinal Charpy V-notch Tests.

c) Metallographic Examination.

7.2 Mechanical Testing and Examination of Weldments

7.2.1 Nondestructive Testing

Welds were evaluated by radiography and/or ultrasonic testing as indicated in 8.2.1.

7.2.2 Small Scale Mechanical Testing of Welds

The following mechanical testing was carried out:

a) Two transverse weld tensile tests (0.50 inch diameter specimen with 2 inch gauge length).

b) Charpy V-notch impact tests: Notches were located at the centerline of the weld, at the fusion line, and in the HAZ at 1, 3, 5,7 and 9 mm from the fusion line.

c) Vickers Traverse of the Weld and HAZ.

7.2.3 Explosion Bulge Tests

Explosion bulge tests were conducted generally following standard procedures (5,6). The weight of the pentolite explosive charge (12 lb.) and the stand off distance (19 in.) to produce an approximate 3% thickness reduction after the initial shot were the same as were previously used for ABS Grade EH36 weldments (Reference 7). Data regarding charge and stand off distance used and thickness reduction obtained for an unwelded EH36 plate are shown in Table 6. A typical set up is shown in Figures 1 and 2.

Each weldment was cooled to 0°F (-18°C), tested (detonation of explosive charge) and subsequently measured and examined for evidence of separation. If separation was observed, the test was terminated. The above testing cycle was repeated until the weldment separation or after three shots.

7.2.4 Metallographic Examination of Weld and HAZ

Polished sections of the weld (including the HAZ) were etched with 2 percent Nital and examined at 100X magnification (see Appendix for discussion and photomicrographs).

8.0 Results and Discussion

8.1 Evaluation of Base Materials

The chemical composition and tensile properties of each base material are shown in Tables 1 and 2. The results of the CVN tests are shown in Table 7 for these candidate steels. Transition curves plotted for absorbed energy and lateral expansion to indicate transition characteristics are shown in Figures 17 and 18.

All results of the tensile and CVN tests met the specification requirements for ABS higher strength steel Grade EH36. The average CVN values of Ti-B treated, Ti-B-REM-V treated and Ti-treated plates were substantially above the ABS requirement for EH36: at -40C 25 ft-lbs minimum for longitudinal specimens (See Table 2).'

The microstructure of all the plates. consisted of fine ferrite and pearlite as shown in Figure 3.

8.2 Evaluation of Weldments

8.2.1 Nondestructive Tests

Radiographic inspection was performed by the shipyard for the ES welds used for large scale 'explosion bulge testing. Ultrasonic inspection was conducted by ABS for all ES welds used for small scale testing and all the CES welds made by the steel manufacturer. All welds met the applicable ABS Class A radiographic or ultrasonic inspection criteria.

8.2.2 Transverse Weld Tensile Tests

The test results are shown in Table 8. All the transverse weld tensile tests met ABS minimum tensile strength requirements for Grade EH36. All fractures occurred in base metal and HAZ locations. However, the tensile strengths of the weld joints for Ti-treated and Ti-B-treated plates are somewhat lower than their base metal strengths. This decrease is attributable to softening[9] of the HAZ with high heat input welding. The decrease could be taken into account by specifying base plate with 75 ksi minimum tensile strength in lieu of 71 ksi minimum for conventional EH36. The loss of strength occurred in Ti-treated and Ti-B-treated steels with thermomechanical control processing (TMCP) and accelerated cooling by water. The loss in strength was not observed in the weld in the Ti-B-REM-V-treated plate produced by thermomechanical control roiling (TMCR) without accelerated cooling. Reference 9 also indicates that a decrease in strength of low carbon equivalent steels may be expected after high temperature reheating treatments such as hot working and stress relief.

8.2.3 Hardness Tests

Vickers hardness surveys taken across the welds and converted to Rockwell B scale are indicated in Table 9 and Figure 19. As would be expected from their lower carbon equivalents, the candidate steels showed less HAZ hardening as compared to the conventional ABS EH36 steel The minimum HAZ hardnesses of Ti-treated and Ti-B-treated weld joints were slightly lower than base metal hardnesses. Ti-B-REM-V-treated plate weld joint did not show lower hardness at the HAZ as compared to the base metal. These results were consistent with the observed reductions of tensile strength noted in 8.2.2.

8.2.4 Charpy V-notch Impact Tests

Results of tests are shown in Table 10. Weldments of all three specially treated steels exhibited HAZ CVN impact energy values considerably above those previously obtained for the conventional EH36 ES weldments (Ref. 7 & 8). All results exceeded the ABS requirements for the EH36 weldments, with the Ti-B-treated steef exhibiting the highest CVN impact values. The EH36 reference weldment exhibited CVN impact values below the requirement of 30 ft-lbs at -20°C.

8.2.5 Explosion Bulge Tests

The results of the explosion bulge tests are shown in Table 11 and photographs of the weldments after the final shot are shown in Figures 10 through 16. The results are summarized as follows:

Ti-treated Steel:

1. ES weldment (480 KJ/in, Figure 10) - The weldment fractured on the second shot at a thickness reduction of approximately 7 percent. The fracture initiated at the weld toe and arrested in base metal forming a "U" shaped path across the weld metal.
2. CES weldment (1252 KJ/in, Figure 11) - This weldment withstood three shots without cracking. A fourth shot did not separate the specimen. The thickness reduction was approximately 15%.

Ti-B-treated Steel:

1. CES weldment (1146 KJ/in, Figure 12) - The weldment fractured on the first shot at a thickness reduction of approximately 3 percent. The fracture initiated in and propagated along the HAZ (for about 1 inch) before branching and arresting in the base metal. The fracture “path” crossed the weld at two locations.
2. ES Weldment (480 KJ/in, Figure 13) - The weldment sustained two shots without fracture and separated along the weld toe on the third shot with approximately 12% reduction in thickness.

Ti-B-REM-V-treated Steel:

1. ES weldment (480 .KJ/in, Figure 14) - The weldment sustained one shot without cracking. On the second shot. a multiypathed, star-type fracture initiated in the base metal about 2 inches from the weld toe. Generally, all fractures arrested in base metal. The fracture paths crossed the weld metal at three locations. After two shots the weldment showed a reduction in thickness of approximately 7 percent.

2. ES weldment (480 KJ/in, Figure 15) - This weldment was exposed to three shots and exhibited approximately 15% thidness reduction with no visible cracks.
3. ES weldment (480 KJ/in, Figure 16) - On the first shot a fracture initiated at and propagated along the weld toe (for about 1 inch) before propagating into and arresting in the base metal forming a "U"-shaped fracture path. The reduction in thickness was approximately 3 percent.

The thickness reduction of the explosion bulge tested candidate steel weldments was considerably in excess of the previously tested electroslag weldments of conventional normalized EH36 steel (Ref. 7) and showed general correlation with thickness reduction results of previously tested manual metal arc and submerged arc weldments of conventional normalized EH36 steel (Ref.'7), which are shown in Table 12. In this regard, the general correlation of the candidate steel weldment results with those obtained for shipbuilding materials and welding processes that have shown satisfactory service experience, strongly indicates that the candidate steels welded by the electroslag processes described herein should also provide satisfactory service.

The candidate steel electroslag weldments exhibited good HAZ toughness; fracture at HAZ locations generally propagated away from the HAZ and arrested in the base metal.' These results were greatly superior to the conventional normalized EH36 electroslag weldments where complete separation along the weld (at the HAZ) occurred on the first shot for three of four test specimens.

9.0 Conclusions

On the basis of this study and the results obtained, the following conclusions are drawn:

1. The three steels studied showed significant resistance to toughness degradation in **the** HAZ when exposed to high heat input welding processes.'
2. The HAZ toughness of three candidate steels welded with a heat input 480 KJ/in. met ABS Grade EH36 weldment requirements.
3. The HAZ toughness of Ti-treated and Ti-B-treated steel welds with consumable nozzle electrosiag (CBS) heat input 1252 KJ/in.'and 1146 KJ/in. respectively, met ABS Grade EH36 weldment requirements.
4. The resistance of the three specially treated steels to HAZ degradation make them attractive for use in applications where HAZ requirements are mandated (as for liquefied gas carriers).'
5. Ti-treated and Ti-B-treated plates (thermomechanical treated and accelerated cooled) exhibited a small loss of strength in the HAZ of high heat input welds. The effect was not observed in the Ti-B-REM-V-treated steel which was thermomechanical treated with no accelerated cooling. Special studies would be required to determine if the above observations were characteristic of the treatments noted.

10.0 Recommendations

It is recommended that specially processed and treated steels of the type investigated be considered for applications, such as liquefied gas carriers where HAZ toughness is a requirement, and for electroslag welding of ABS higher strength steels..

APPENDIX

Commentary on the Effects of Chemical Composition and Manufacturing Processes on HAZ Toughness of Microalloyed Steels.'

The HAZ toughness of normalized, vanadium or niobium treated steels, such as Grade EH36 is impaired when welded with high heat input processes. At a temperature of 1050°C dispersed niobium or vanadium carbides, nitrides or carbo-nitrides dissoive(10,11). This decrease in the amount of the precipitates, which function as grain growth inhibitors and strengtheners, is a factor in the resultant degradation of HAZ properties. The reduced Charpy V-notch HAZ toughness developed by high heat input welding is considered partly related to grain growth and partly related to the resultant microstructure. In order to obtain adequate HAZ toughness, good weldability and adequate base material characteristics, consideration is generally given to the following:

A) Chemical Composition

1) Carbon Equivalent - It is generally recognized that- the most effective way *to* improve weldability is to lower the carbon equivalent, and thereby reduce the likelihood of untempered martensite formation, with its attendant high hardness and low notch toughness. Table 5 of the test indicates that ail three candidate steels investigated had significantly lower carbon equivalents than that of conventional, normalized EH36 whose Ceq was 0.46. The carbon equivalents of TI-treated, Ti-B-treated and Ti-B-REM-V-treated plates were 0.30%, 0.31% and 0.35% respectively. This low carbon equivalent is a contributing factor in the superior HAZ

toughness for the subject steels as compared with the conventional, normalized EH36 steel.

2) Grain Refinement in HAZ - For Ti-treated steel, austenite grains can be refined through “pinning” ability of finely dispersed titanium nitrides (TiN). Fine TIN precipitates, smaller than 0.05mm in size, remain undissolved at 1400°C(12)and are effective in retarding austenite grain coarsening. The stoichiometric ratio of Ti to **N** should be equal to or no more than 3.5:i. In addition, calcium or magnesium may also be used together with Ti (or Zr) to form fine precipitates(1[3])for inhibiting grain growth. Very fine Ca or **Mg** inclusions serve as nucleation sites for TiN precipitate. In the case of Ti-B-REM-V treated steels, the rare earth metal forms globular inclusions[(3)]of cerium sulphides ($Ce2^{S}5$)and oxysulphides ($Ce2^{O}2^{S}$) which are resistant to deformation during hot rolling and maintain their globular form, unlike manganese and iron sulphides which elongate. The favorable effect of. globular inclusions and increased cleanliness of the grain boundaries generally improves toughness in the HAZ. With optimized Ce additions, rapid grain growth is retarded up to 1200°C(14). Boron also refines ferrite grains by creating ferrite nucleation sites of BN.

3) Lowering Impurity Content - Reducing sulfur, phosphorus, nitrogen and oxygen in a steel improves toughness in both the base metal and HAZ. The sulphide or phosphide formed in steel with a lower melting point can dissolve and precipitate in the grain boundaries in the overheated HAZ. All three candidate steels had approximately the same amount of phosphorus as EM36 materials shown in Table 5. However, the sulfur content for all three candidate steels is considerably less than EH36.

8) Manufacturing Process

To enhance weldability, all candidate steel had been formulated' with a lower carbon equivalent than conventional, normalized EH36 steel. A drawback associated with lowering of the carbon equivalent is a commensurate reduction of base metal strength. This drawback can be alleviated by plate rolling practices that afford strict control of rolling temperature, rolling reduction ratios and accelerated cooling of the finished plate.

The Ti-treated plates and the Ti-B-treated plates had been manufactured by Thermomechanical Control Processing (TMCP); the Ti-B-REM-V-treated plates had been manufactured by Thermomechanical Control Rolling (TMCR) process.

In both TMCP and TMCR the first stage rolling is conducted in the recrystallized austenite region between - 115O°C and 95O°C, to produce fine austenite grains. The second stage roiling is performed in the non-recrystallized austenite . region between 950°C and- 75O°C. The rolling reduction in this

region induces deformation bands; consequently, during austenite-ferrite transformation, ferrite is generated not only from the initiation site of the austenite grain boundaries but also from deformation bands produced by roiling in the non-recrystallization zone, resulting in a finer grain structure. The above two steps are similar to conventional controlled rolling (CR); TMCP and TMCR differ from CR in that after second stage rolling, the following additional processing is applied.

TMCP: Accelerated cooling by water, carried out after CR; this enhances mechanical properties.

TMCR: A third stage rolling in the austenite-ferrite two phase region after CR; this enhances mechanical properties.

C) HAZ Microstructure

Conventional ordinary and higher strength steels welded with electroslag exhibit coarsened grains in the HAZ. These coarse grains are delineated by proeutectoid ferrite which nucleates at, and grows from the austenite grain boundaries. Also a large amount of Widmanstatten secondary ferrite plates develop from grain boundaries (see Reference 7 of text). In general, the mixed structure of coarse mesh-like proeutectoid ferrite and Widmanstatten side plates result in low toughness.'

Macrosections representative of each candidate steel weldment are shown in Figure 4. Photomicrographs of the weld metal and HAZ representative and illustrated in Figure 5 through 9 for candidate steels. The photomicrographs

reveal uniform microstructures consisting of relative fine acicular ferrite and pearlite instead of coarse intermediate stage structures for conventional ‘ordinary and higher strength steels in the HAZ. Because of the effect of the low carbon content(15)or pinning effect of TiN, generation of ferrite in the austenite grin boundary and intragranular ferrite side plate was suppressed, resulting in a significant improvement in HAZ toughness. The results of Charpy and bulge tests confirm this.’

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TABLE 1 CHEMICAL COMPOSITION OF BASE MATERIAL

late Type	Chemical Composition %															
	C	Mn	Si	P	S	Al	Ti	Cu	Ni	Cr	Mo	V	Cb	B	REM	Ceq*
ABS EH 36 (Ref.7)	0.18	1.44	0.27	0.009	0.02	0.043		0.03		0.17	0.005		0.036			0.46
i-treated	0.12	1.05	0.20	0.011	0.003	0.035	0.009									0.30
i-B-treated	0.08	1.38	0.27	0.007	0.001	0.054	0.007							0.0011		0.31
i-B-REM-V treated	0.08	1.54	0.46	0.01	0.001	0.026	0.008					0.042		0.0013	0.007	0.35
BS Req't. EH36	0.18 max.	0.90–1.60	0.10–0.50	0.04 max.	0.04 max.			0.35 max.	0.40 max.	0.25 max.	0.08 max.	0.01 max.	0.05 max.			

Note * Ceq = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5

TABLE 2 TENSILE PROPERTIES OF BASE MATERIALS[1,2]

Plate	EH36 (Ref.7) Killed Fine grain Normalized	Ti-treated Killed Fine grain TMCP	Ti-B-treated Killed Fine grain TMCP	Ti-B-REM-V treated Killed Fine grain TMCR
Tensile Strength(ksi)	73.7	73.2	75.5	71.2
Yield Point (ksi)	51.3	51.8	60.6	52.7
Elongation in 2 in.	30.0	35.5	32.5	36.0

Note (1) Average of 2 tests.

(2) ABS Requirement for X36

Tensile Strength (ksi)	71-90
Yield (ksi, min.)	51
Elongation in 2 inches (% min.)	22
CVN Impact Test	
Temperature (°C)	-40
Energy - (ft-lbs,Avg.Min)	
Longitudinal Specimen	25
or	
Transverse Specimen	17

TABLE 3 WELDING PARAMETERS FOR ELECTROSLAG WELDING (ES) BY SHIPYARD

Steel	ABS Grade EH36	Ti-treated	Ti-B-treated	Ti-B-REM-V treated
Filler Wire	Linde MI88	Linde MI88	Linde MI88	Linde MI88
Flux	Linde 124	Linde 124	Linde 124	Linde 124
Wire Size (in.)	3/32	3/32	3/32	3/32
Current (A)	390	500	500	500
Voltage. (V)	37	40	40	40
Travel Speed (in./min.)	2	2-l/2	2-l/2	2-l/2
Approx. Heat Input (Kilo Joule/in.)	432	480	480	480
Plate Thickness (in.)	1-l/4	l-3/8	l-1/4	l-1/4

Joint Design

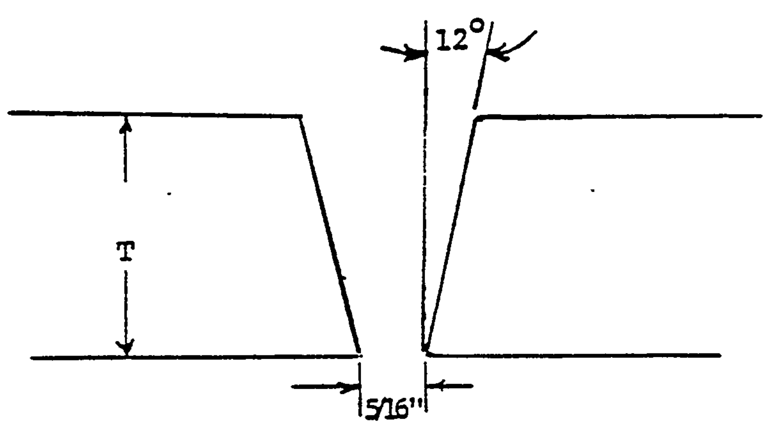


TABLE 4 WELDING PARAMETERS FOR CONSUMABLE NOZZLE ELECTROSLAG WELDING (CES) BY STEEL MANUFACTURER

Steel	Ti-treated	Ti-B-treated
Filler Wire	A	A
Consumable Nozzle	B	C
Flux	D	D
Wire Size (mm)	2.4	2.4
Nozzle Size (mm)	12	12
Current (A)	450	400
Voltage (V)	42	40
Travel Speed (in./min.)	0.906	0.839
Approx. Heat Input (Kilo-Joule/in.)	1252	1146
Plate Thickness (in.)	l-3/8	l-1/4

Joint Design

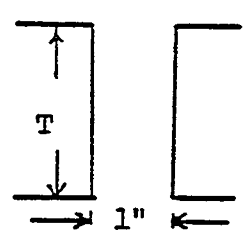


TABLE 5 CHEMICAL COMPOSITION OF FILLER WIRE

Electrode	Welding Process	C	Mn	Si	P	S	Cr	Ni	Mo	Cu
Linde MI88	ES	0.04	1.65	0.35			0.25	1.5	0.4	
A	CES	0.07 1 0.13	1.35 1 2.00	0.08 max.	0.02 max.	0.023 max.	0.15 max.		0.40 1 0.60	0.15 Max.

TABLE 6 EXPLOSION BULGE TEST - CHARGE AND STAND OFF DISTANCES VS DEFORMATION

Grade	Thickness (in.)	Test Temp. (F)	Stand Off Distance (in.)	Charge (lb.)	Shot No.	% Reduction		Depth of Bulge (in.)		Remarks
						A	B	A	B	
EH36 (Unwelded plate)	1-1/4	-20 (-29C)	19	12	1	2.8	3.2	1.2	1.2	No cracks
					2	6.2	5.9	2.1	2.1	No cracks
					3	9.7	8.6	2.7	2.0	No cracks

TABLE 7 INDIVIDUAL CHARPY V-NOTCH TEST RESULTS ON BASE PLATES

Plate	Test Temperature (C°)	Energy Absorbed (ft-lbs)	Shear Fracture Appearance (%)	Lateral Expansion (MILS)
EH36	-29	103, 98, 101 98, 107	100, 100, 100 100, 100	69, 72, 70 69, 70
	-40	67, 7.0, 69 49, 66	50, 60, 65 50, 60	53, 54, 52 40, 52
	-62	37, 36, 33 30, 19	5, 10, 25 15, 5	21, 28, 43 23, 16
	-73	15, 25, 14	2, 5, 2	10, 18, 9
Ti-Treated	-20	125, 127, 184	100, 55, 100	81, 82, 82
	-40	86, 85, 68	10, 10, 10	66, 65, 57
	-60	6, 43, 46	0, 5, 0	4, 41, 37
	-80	29, 11, 10	5, 5, 0	24, 7, 6
	-100	2, 3, 6	0, 0, 0	4, 0, 0
Ti-B-Treated	-20	262*, 262*, 262*	100*, 100*, 100*	
	-40	262*, 262*, 262*	100*, 100*, 100*	91*, 90*, 99*
	-60	262 '169 ,262	100 , 60, 100	88, 94 , 92
	-80	19, 81, 39	0, 60, 10	17, 76, 38
	-100	9, 9, 27	5, 0, 5	9, 9, 28
	-120	4, 4, 4	0, 0, 0	4, 1, 1
Ti-B-REM V-Treated	-20	262*, 262*, 262*	100*, 100*, 100*	106*, 81*, 103*
	-40	126, 262*, 98,	50, 100*; 50	95, 103*, 67*
	-60	100, 55, 262	30, 10, 100	82, 47, 85
	-80	8, 100, 7	5, 40, 5	7, 73, 07
	-100	4, 5, 4	0, 0, 0	0, 2, 1

NOTE: * Partial break. Maximum test machine capacity 264 ft-lbs.
Data for information only: not valid according to ASTM E23.

TABLE 8 ELECTROSLAG WELD TRANSVERSE
TENSILE PROPERTIES #

WELDMENT BASE METAL	HEAT INPUT (KJ/IN.)	TENSILE STRENGTH (KSI)	FRACTURE LOCATION
ABS EH36 (Ref.7)	432	82.4, 81.5	Base Metal
Ti-treated	480	69.5, 71.0	HAZ
	1252	68.0, 69.5	HAZ
Ti-B-treated	480	68.0*, 67.7*+	HAZ
	1146	71.4, 70.0	HAZ
Ti-B-REM-V-treated	480	73.6, 74.3	Base Metal
ABS Req't EH36		68-90	Base Metal

Note: # For base metal tensile strengths, see Table 2
* Steel manufacturer's test data
+ Considered (68 ksi)

TABLE 9 VICKERS HARDNESS TRAVERSE ACROSS WELDS
HARDNESS CONVERTED TO ROCKWELL "B" NUMBERS

Plate	EH36	Ti-treated	Ti-treated	Ti-B-treated	Ti-B-treated	Ti-B-REM-treated
Heat Input KJ/in.	432	1252	480	480	1146	480
Specimen No.	E7	M36	N1	M52	M56	M64
Base Metal	82	82	80	79	80	81
11 mm from F.L.	84	79	76	81	76	86
9 mm from F.L.	86	80	76	81	76	83
7 mm from F.L.	87	78	76	80	77	81
5 mm from F.L.	90	80	76	81	78	84
3 mm from F.L.	95	80	77	82	79	84
1 mm from F.L.	96	85	82	86	83	88
Fusion Line	98	87	86	91	83	87
Weld Metal	99	89	90	90	94	94
Fusion Line	96	83	87	89	87	90
1 mm from F.L.	96	74	83	80	84	93
3 mm from F.L.	94	78	77	78	80	87
5 mm from F.L.	90	77	76	77	76	86
7 mm from F.L.	86	76	76	76	77	85
9 mm from F.L.	86	77	75	73	79	85
11 mm from F.L.	84	76	77	75	81	84
Base Metal	82	79	79	80	77	78

TABLB 10 INDIVIDUAL CHARPY V-NOTCH TEST RESULTS
FOR ELECTROSLAG WELDS

Plate	Heat Input KJ/in.	Test Temp °C	Absorbed Energy (ft-lbs) Weld	F.L.	HAZ 1 mm	HAZ 3 mm	HAZ 5 mm	HAZ 7 mm	HAZ 9 mm	Base Metal
EH36 (Ref.7&8)	315	-20	33, 31, 31	23, 29, 22	12, 10, 10	89, 93, 99	74, 78, 77	93, 95, 85		88, 90, 91
	432	-40	25, 25, 30	30, 49, 57	7, 8, 10	19, 22, 17	98, 101, 101	98, 74, 97	112, 98, 105	67, 70, 69
			30, 35, 20	5, 8, 8	6, 7, 9	8, 22, 6	68, 67, 101	99, 100, 86	100, 79, 108	49, 66
Ti-treated	480	-20	23, 22, 35	47, 24, 147	112, 128,24	116, 134,140	122, 234+, 240+	262*, 262*, 262*	262*, 262*, 262*	101, 124, 135
		-40	14, 14, 14	72, 17, 89	96, 90,84	92, 114, 96	255*, 262*, 258+	262*, 258*, 262*	262*, 262*, 262*	
	1252	-20	33, 31, 15	143, 64, 93	42, 82, 113	98, 114, 219+	253*, 262*, 252*	262*, 262*, 262*	262*, 222, 262*	175, 127, 184
			22, 28, 66	86, 76, 25	227, 28, 132					
		-40	9, 11, 13	13, 12, 15	24, 110, 112	24, 101, 199+	217+, 258*, 215+	262*, 262*, 262*	262*, 262*, 262*	86, 85, 68
Ti-B-treated	480	-20	86, 49, 77	262*, 262*, 262*	56, 260*, 262*	262*, 262*, 262*	262*, 262*, 262*			262*, 262*, 262*
		-40	38, 34, 24	46, 28, 89	261*, 262*	262*, 262*, 262*	262*, 262*, 262*			262*, 262*, 262*
	1146	-20	84, 69, 71	262*, 120, 260*	261*, 262*, 262*	262*, 261*, 262*	262*, 262*, 262*			262*, 262*, 262*
		-40	114, 262*, 60	76, 30, 52	262*, 262*, 262*					
				120						
Ti-B-REM-V treated	480	-20	33, 38, 34	132, 35, 131	62, 48, 20	259*, 99, 155	262*, 150, 262*			262*, 262*, 262*
			49, 64, 52	17, 50, 43	262*, 104, 35					
		-40	25, 24, 33	17, 78, 16	126, 100, 80	51, 21, 65	105, 15, 82			126, 262*, 127

Note * Maximum test machine cnpacity 264 ft-lbs., partial break.
Data for information only) not valid according to ASTM E23.

+ Energy value above 00% of the test machine scale range is considered approximate according to ASTH E23.

TABLE 11 EXPLOSION PULCE TEST RESULTS FOR ES WELDS

Plate	Specimen No.	Heat Input	Shot No.	Thickness Reduction % A	Thickness Reduction % B	Depth of Bulge (in.) A	Depth of Bulge (in.) B	Longest Crack (in.)	Remarks
EH36	E-7	432	1	3.2	3.6	1.3	1.3	-	No visible cracks
			2	6.4	7.2	2.3	2.3	-	No visible cracks
			3	-	10.2	-	-	5.5	Large piece broke out of center area. Separation along weld A side right of center from hole to 1.8 in. of left edge along the weld part of this distance. 5 cracks radiating from center area into base material with longest 5.5 in.
EH36	E-7A	432	1	3.3	3.6	1.4	1.3	10.0	Plate separated along weld from right of center of left edge. Crack across the weld into base material 8 in. long. 3 other cracks from center area into base material 3.2 to 3.5 in. long.
EH36	E-8	432	1	2.9	2.7	1.5	1.5	Plate Separated	Plate separated along weld with 2 small cracks into base material from weld.
EH36	E-8A	432	1	1.4	1.1	2.0	1.7	Plate Separated	Plate separated along weld.
Ti-Treated	H36-1	480	1	3.2	2.7	1.3	1.3	-	No visible crack
			2	7.4	6.5	2.6	2.5	17.38	Mainly U shaped tear from 4" right of center across weld into base material A side 9-5/8" B side 7-3/4". Crack from 4" right of center from 3/4" from toe of weld. 2" long on A side and 1-1/2" into base material B side.
Ti-Treated	H36	1252	1	3.2	3.7	1.2	1.2	-	No visible crack
			2	9.7	9.5	2.2	2.1	-	No visible crack
			3	11.1	11.2	2.7	2.7	-	No visible crack
			4	17.2	15.0	3.3	3.2	-	No visible crack
Ti-B-Treated	H56	1146	1	3.7	1.7	2.1	1.8	9.75	Crack A side toe of weld from 1" left of center to 3-3/4" left of center. Tear radiating from one end - 1" left center into base material A side 2-1/4" and B 2-1/4", and from another end - 3-3/4" left of center into base material A side 2-5/8" and B side 1-1/2".
Ti-B-Treated	H52	480	1	5.0	3.9	1.6	1.5	-	No visible crack
			2	9.0	9.3	2.6	2.4	-	No visible crack
			3	12.3	11.3	3.3	3.5	18.0	Plate separated along weld on A side from right edge of plate to 2" from left edge.

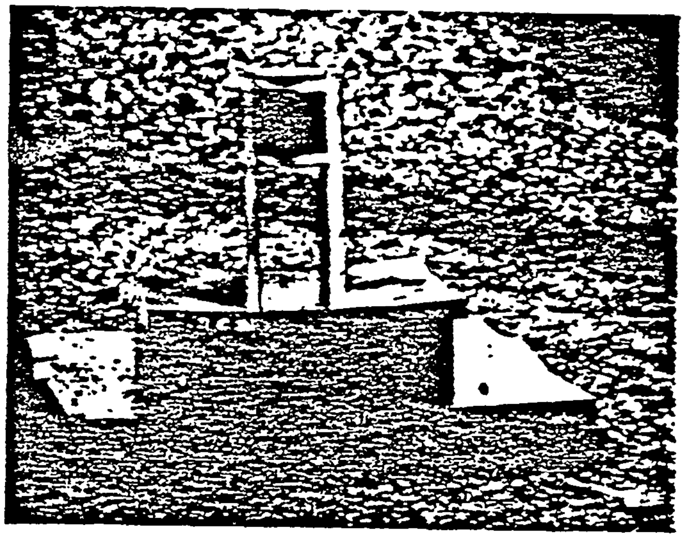
TABLE 11 *EXPLOSION* BULGE TEST RESULTS FOR ES WELDS (CONT'D)

Plate	Specimen No.	Heat Input (kJ/in.)	Shot No.	Thickness Reduction % A	Thickness Reduction % B	Depth of Bulge (in.) A	Depth of Bulge (in.) B	Longest Crack (in.)	REMARKS
T1-B-REM-V Treated	**K-1**	**480**	**1**	**5.9**	**6.3**	**1.6**	**1.6**	**-**	**No visible crack**
			2	**7.5**	**7.2**	**-**	**-**	**6.0**	**Plate failed in center with numerous tears radiating from toe of weld A side. Crack A side from 4" left of center into base material 1-1/4" propagating to 1/2" from edge of left side.**
T1-B-REM-V Treated	**K-2**	**480**	**1**	**3.2**	**3.8**	**1.6**	**1.6**	**-**	**No visible crack**
			2	**7.5**	**7.0**	**2.6**	**2.5**	**-**	**No visible crack**
			3	**15.3**	**14.8**	**3.4**	**3.2**		**No visible crack**
T1-B-REM-V Treated	**K-3**	**480**	**1**	**4.7**	**2.7**	**1.9**	**No reading Broken**	**11.25**	**U shaped tear B side from center into base material left 6-3/4" center to right 4-1/2". Crack B side 1-1/2" from weld, 1-1/2" from center to right 7-1/2".**

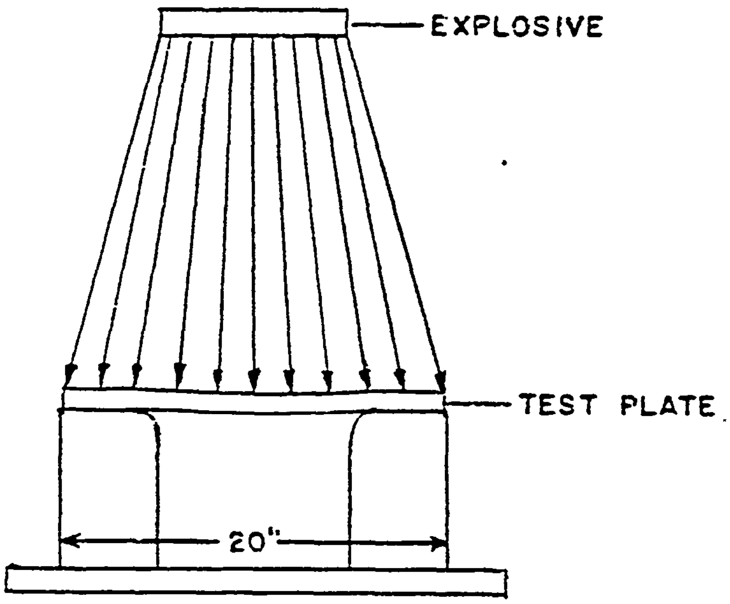
Note: All tests conducted at temperature of OF (-18C).

TABLE 12

Specimen No.	Welding Method	Heat Input (KJ/in.)	Shot	% Thickness Reduction A	% Thickness Reduction B	Depth Bulge(in.) A	Depth Bulge(in.) B	Longest Crack (in.)	Remarks
E-l	MMA	66	1	3.5	3.9	1.4	1.4		No visible cracks
			2	6.6	7.4	2.3	2.4		No visible cracks
			3	-	-	-	-		Entire center area blew out.
E-2	MMA	66	1	2.9	3.0	1.3	1.3		No visible crack
			2	7.2	6.7	2.4	2.3		No visible crack
			3	10.3	10.4	3.0	3.0		No visible crack
E-5	SAW	79	1	3.1	3.0	1.3	1.3		No visible crack
			2	6.8	6.7	2.3	2.2		No visible crack
			3	10.1	10.2	2.3	2.2		No visible crack
E-6	SAW	79	1	2.8	3.1	1.1	1.1		No visible crack
			2	6.3	6.0	2.2	2.2		No visible crack
			3	10.1	10.2	3.0	3.0		No visible crack

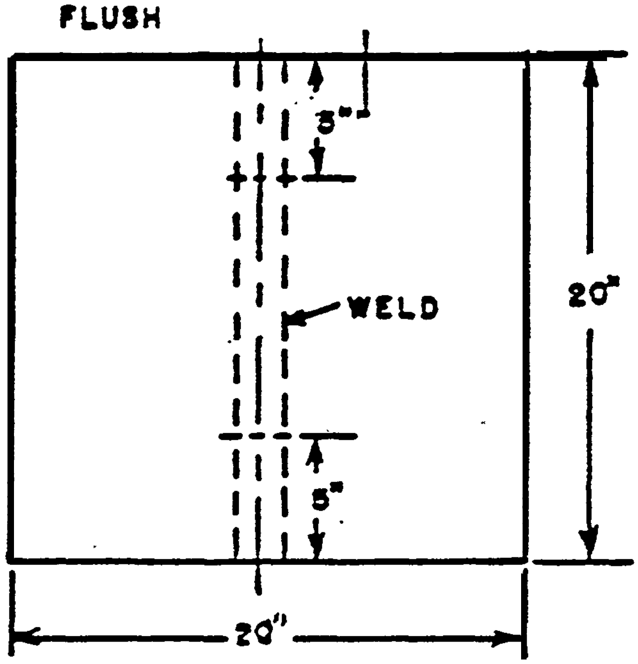


PHOTOGRAPH OF EXPLOSIVE CHARGE, SPECIMEN AND DIE



SCHEMATIC DRAWING OF EXPLOSION BULGE TEST

FIGURE 1 - TYPICAL EXPLOSION BULGE SET-UP



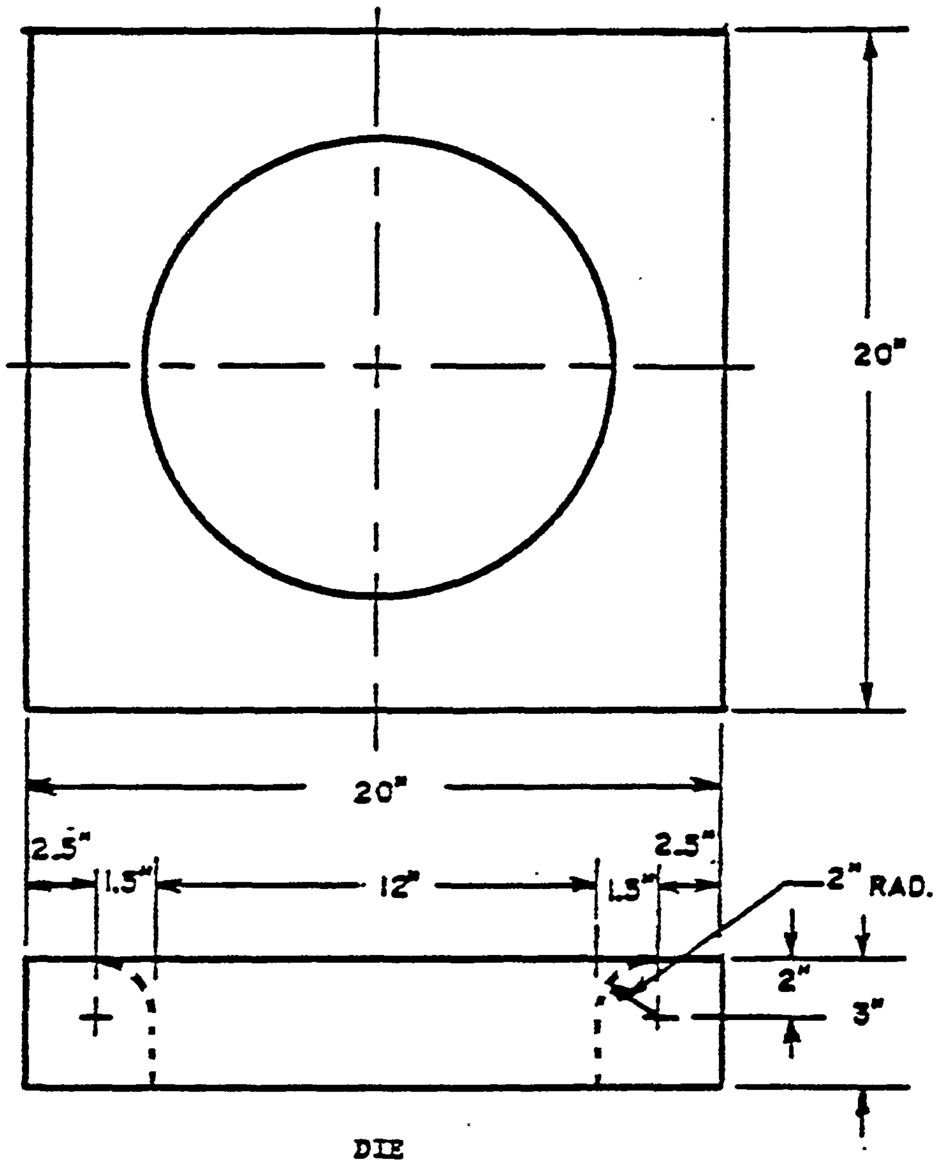
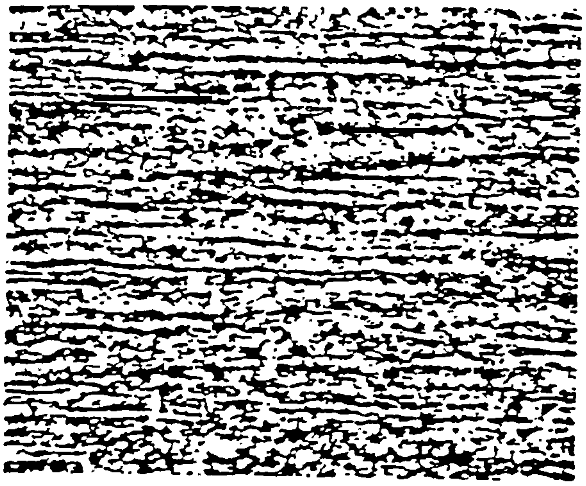
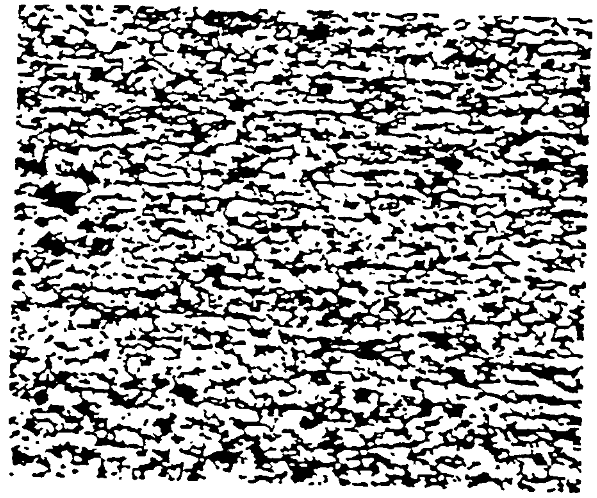


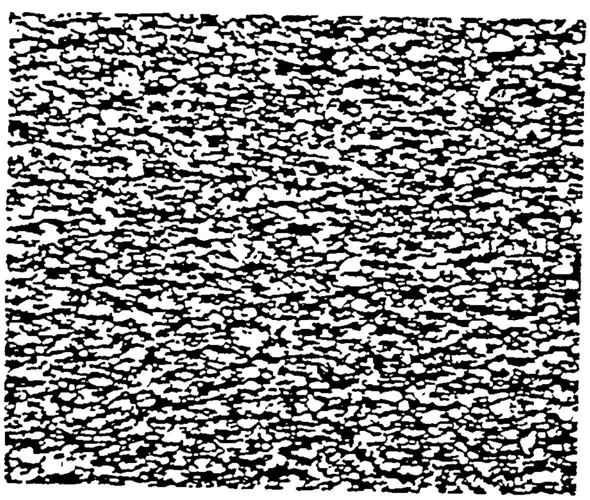
FIGURE 2 EXPLOSION BULGE SPECIMEN AND DIE



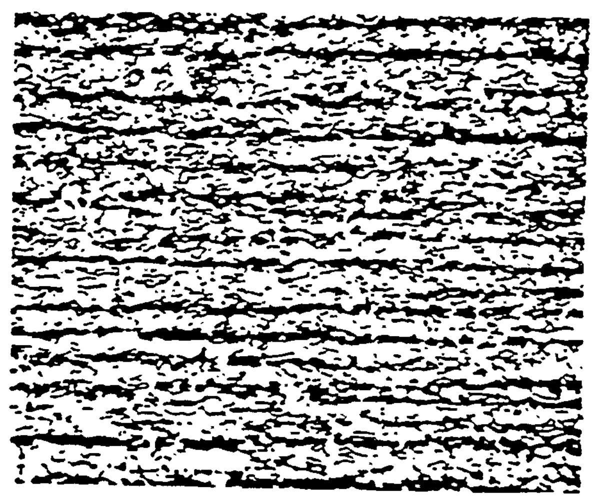
EH36



TI-TREATED



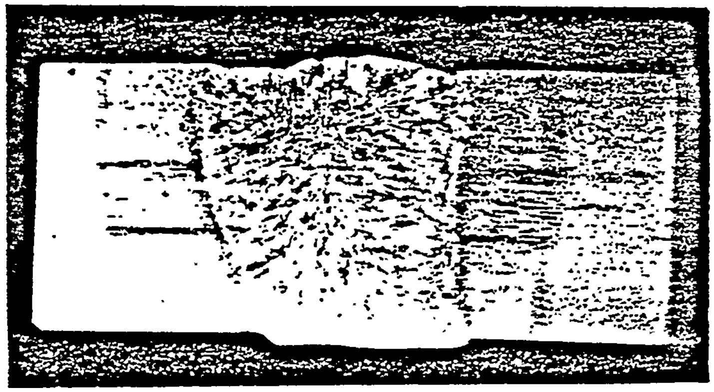
TI-B-TREATED



TI-B-REM-V-TREATED

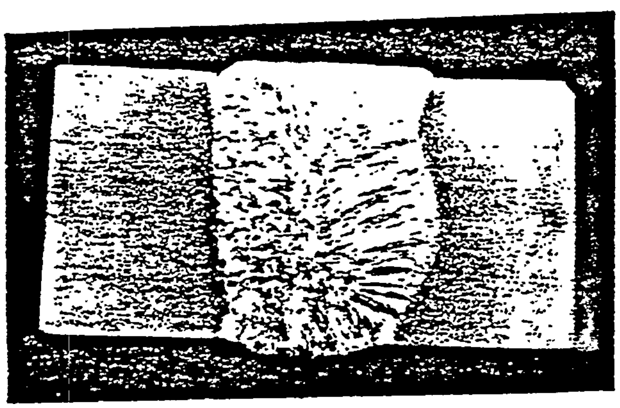
(2% NITAL ETCH, 100X)

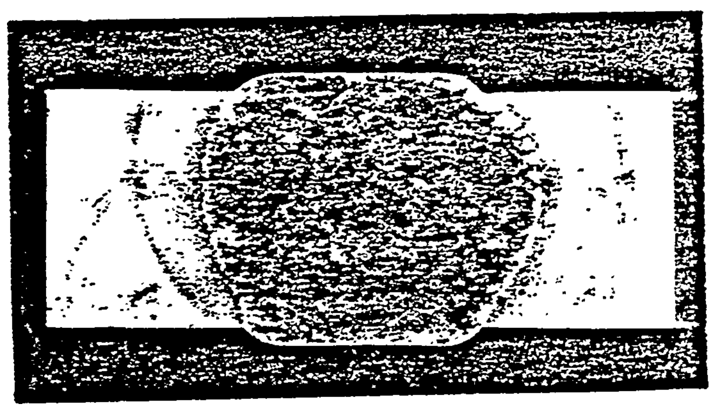
FIGURE 3 BASE METAL MICROSTRUCTURE



480 KJ/IN., TI-B-REM-V-TREATED

480 KJ/IN. TI-TREATED **1252** KJ/IN.

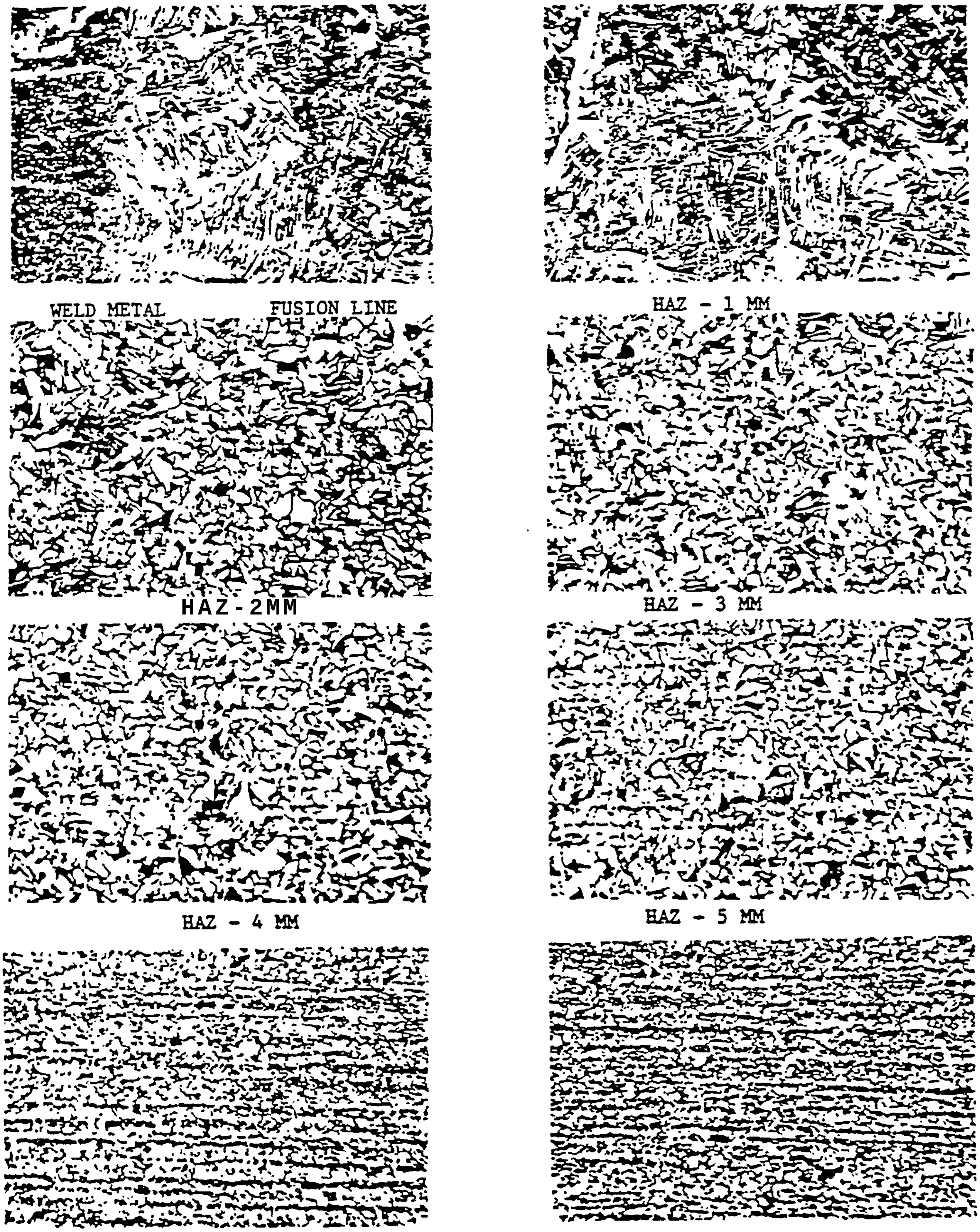




480 KJ/IN. TI-B-TREATED 1146 KJ/IN.

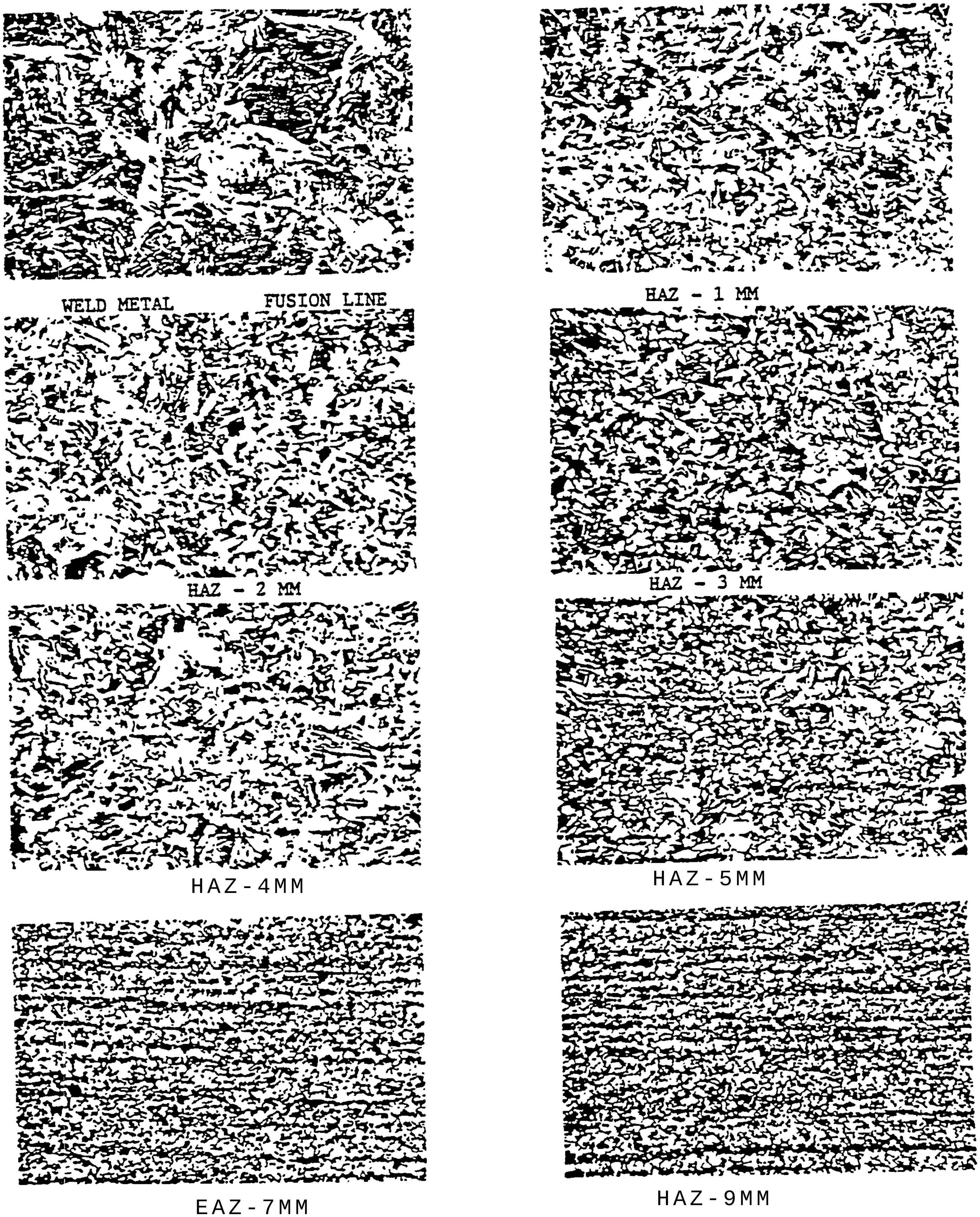
(10% NITAL ETCH, ACTUAL SIZE)

FIGURE 4 MACROSECTION OF WELDS



(480 KJ/IN., 2% NITAL, 100X)

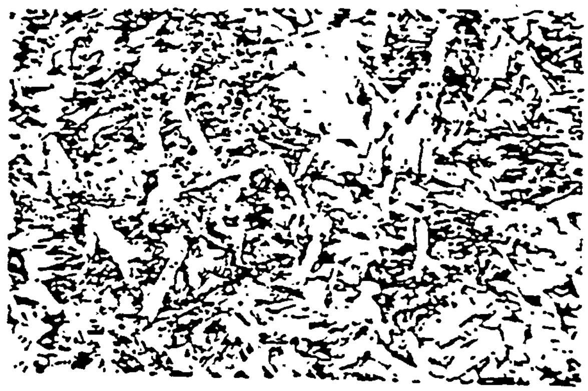
FIGURE 5 PHOTOMICROGRAPHS OF ES WELDMENT IN TI-TREATED STEEL



(1252 KJ/IN., 21. NITAL, 100X)

FIGURE6 PHOTOMICROGRAPHS OF CES WELDMENT IN TI-TREATED STEEL

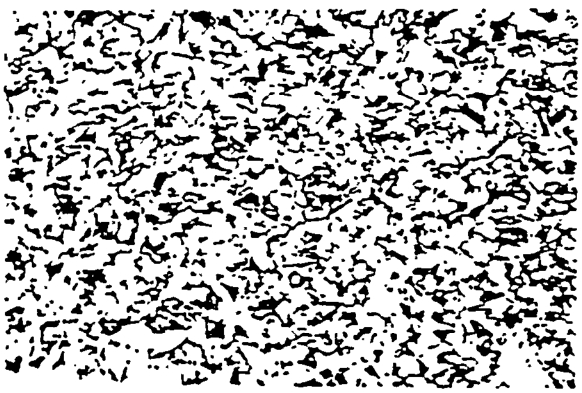
WELD METAL FUSION LINE



HAZ - 1 MM

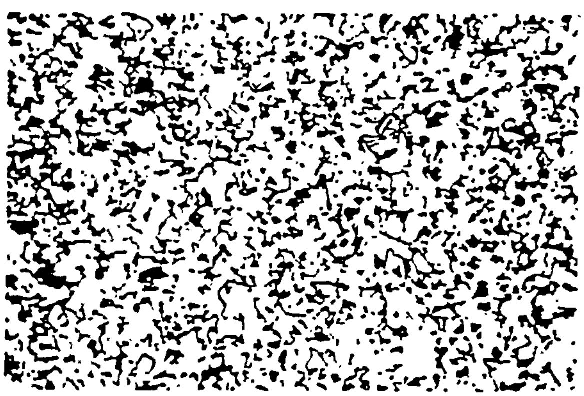
HAZ - 2 MM

HAZ - 3 MM



HAZ-4MM

HAZ - 5 MM

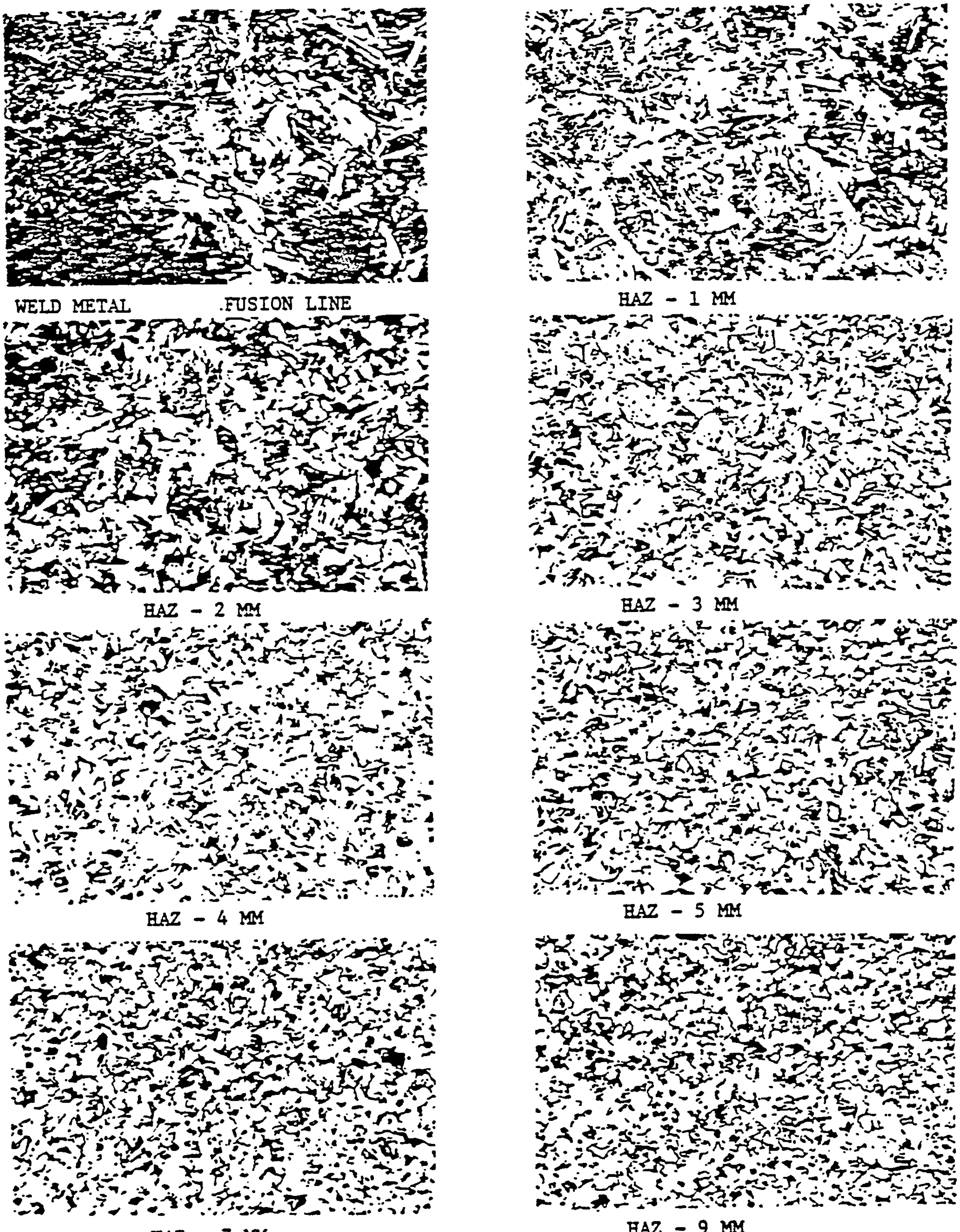


HAZ-7MM

HAZ-9MM

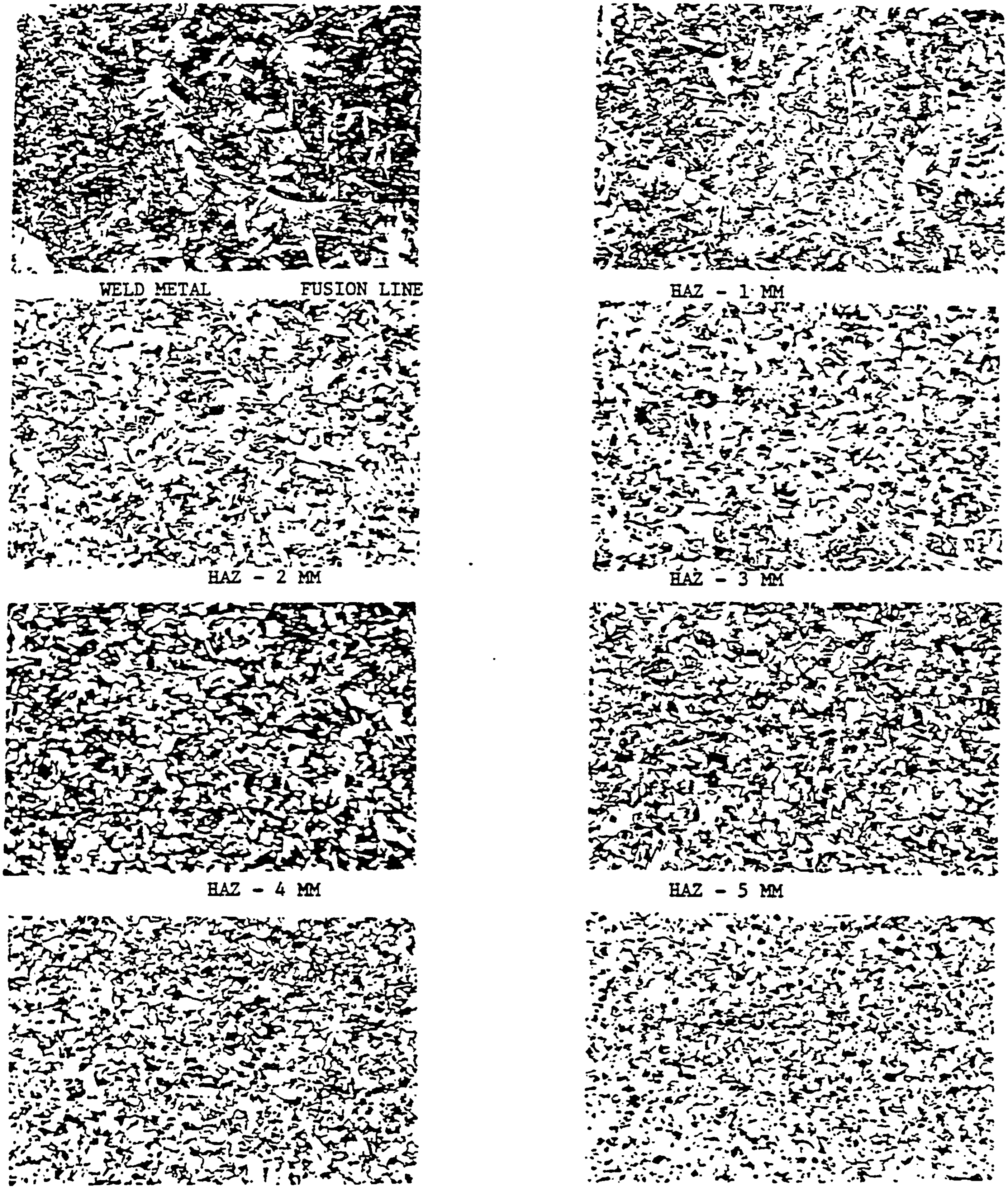
(480 KJ/IN., 22 NITAL, 100X)

FIGURE 7 PHOTOMICROGUPHS OF ES WELDMENT IN TI-B-TREATED STEEL



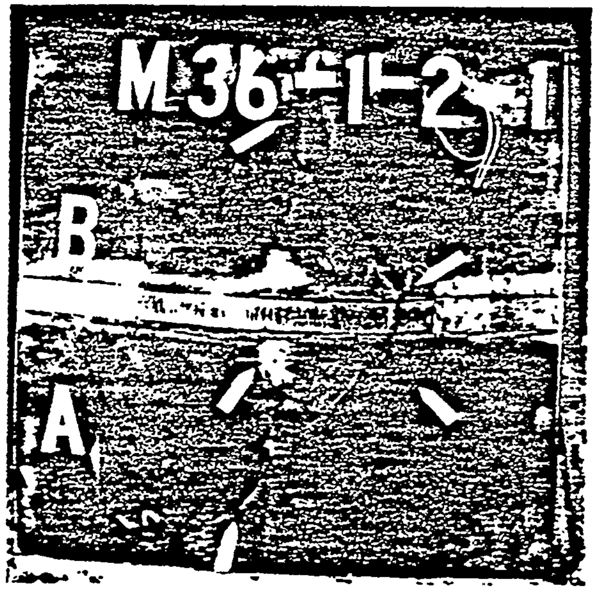
(1146 KJ/IN., 2% NITAL ETCH, 100X)

FIGURE 8 PHOTOKKROGICAPHS OF CES WELDMENT IN TI-B-TREATED STEEL

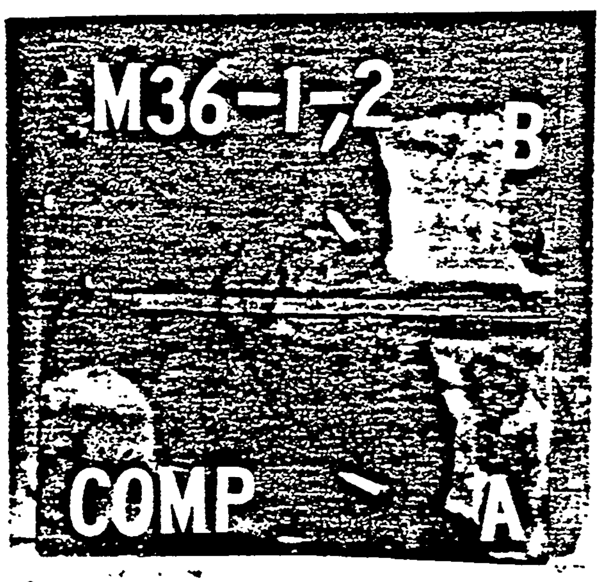


(480 KJ/IN. , 2% NITAL ETCH, 100X)

FIGURE 9 PHOTOMICROGRAPHS OF ES WELDMENT IN TI-B-REM-V-TREATED STEEL



TENSION SIDE



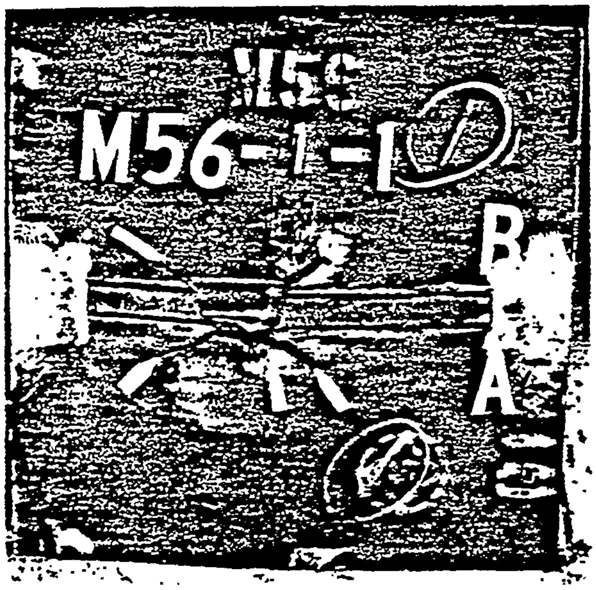
COMPRESSION SIDE

(NO. M36-1 AFTER 2 SHOTS, TEST TEMP. 0°F)

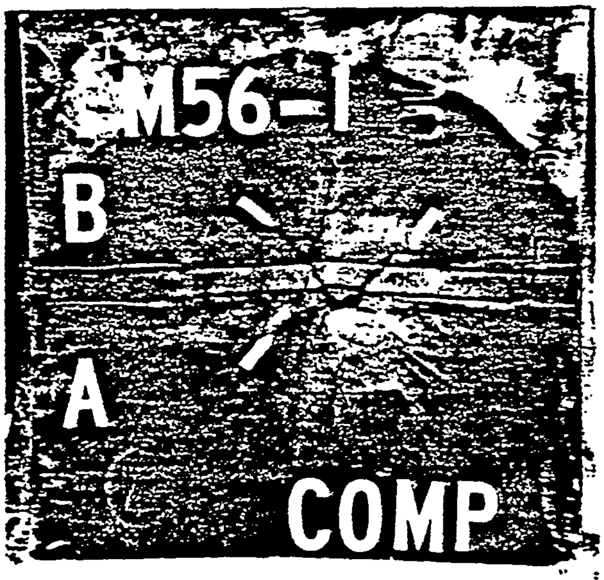
FIGURE 10 ES TI-TREATED STEEL EXPLOSION BULGE SPECIMEN

(NO. M36 AFTER 4 SHOTS, TEST TEMP. 0°F)

FIGURE 11 CES TI-TREATED STEEL EXPLOSION BULGE SPECIMEN



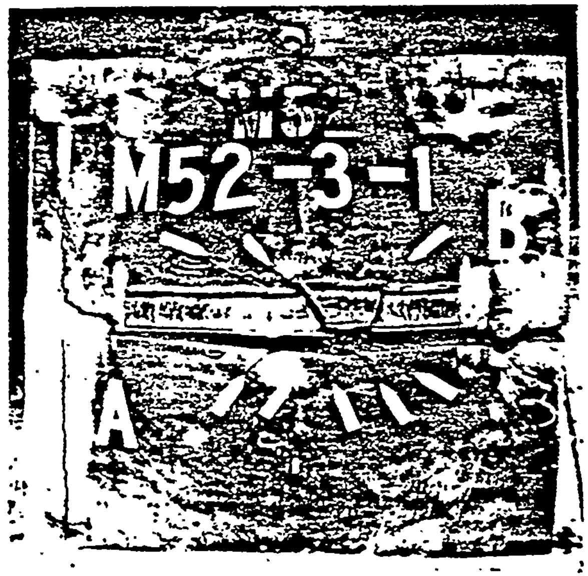
TENSION SIDE



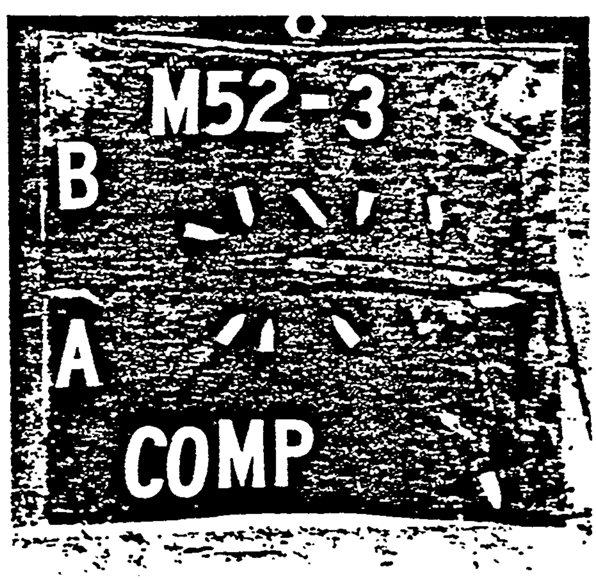
COMPRESSION SIDE

(NO. *MS6* AFTER 1 *SHOT,* TEST TEMP. 0°F)

FIGURE 12 CES TI-B-TREATED STEEL EXPLOSION BULGE SPECIMEN



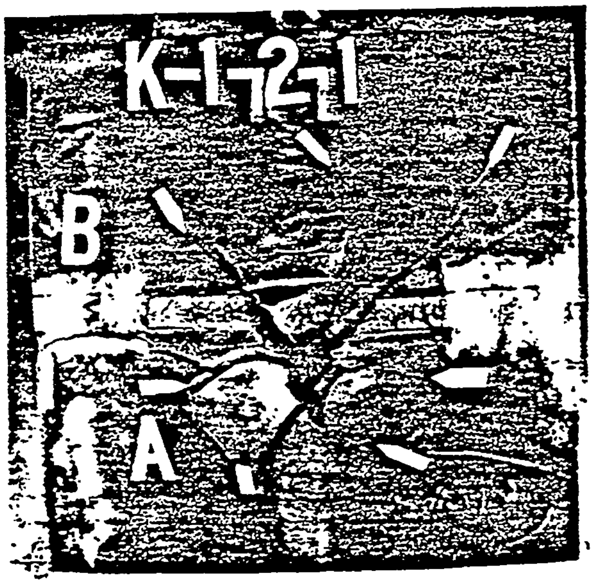
TENSION SIDE



COMPRESSION SIDE

(NO. M52 AFTER 3 SHOTS, TEST TEMP. 0°F)

FIGURE 13 ES TI-TREATED EXPLOSION BULGE SPECIMEN

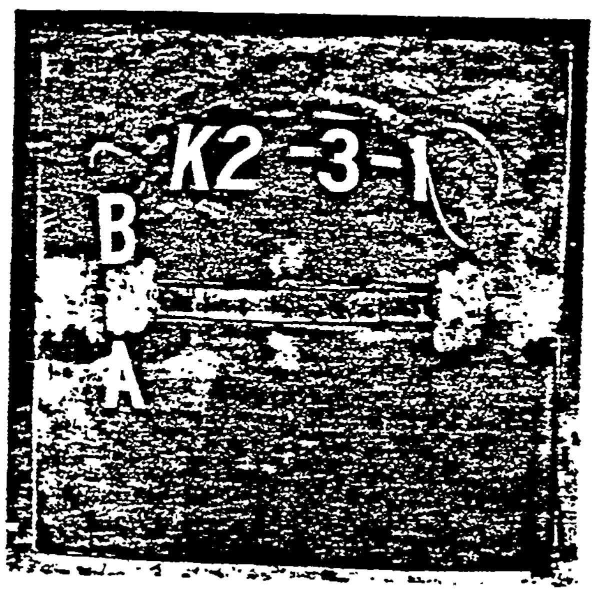


TENSION SIDE

COMPRESSION SIDE

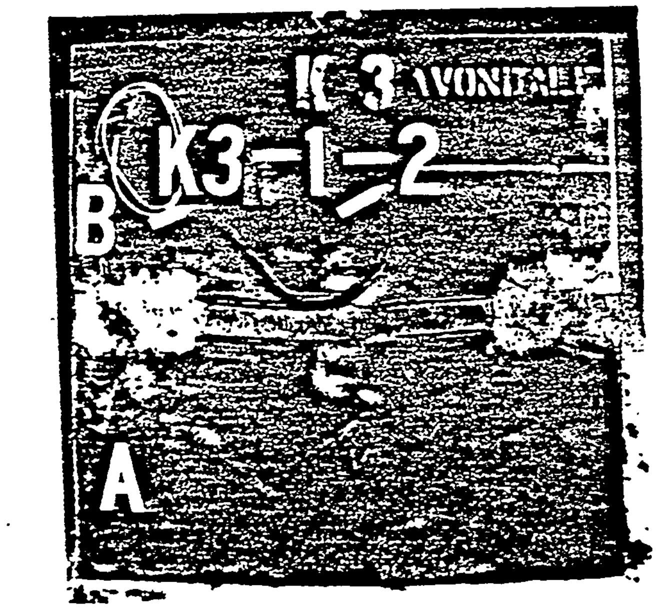
(NO. K1 AFTER 2 SHOTS, TEST TEMP. 0°F)

FIGURE 14 ES TI-B-REM-V-TREATED STEEL EXPLOSION BULGE SPECIMEN

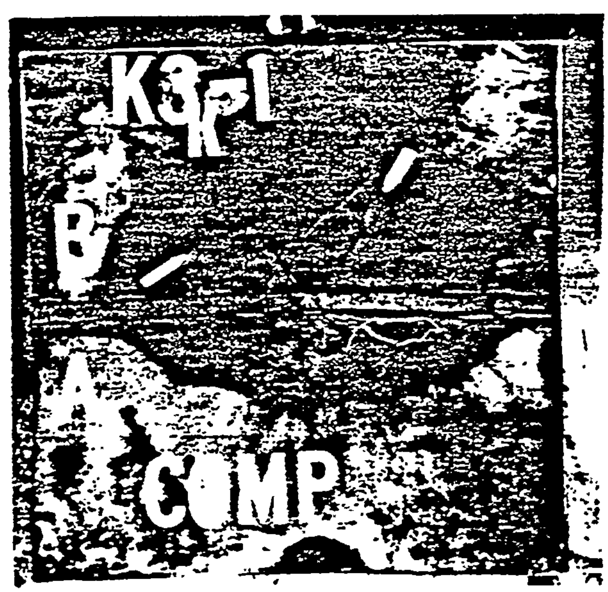


(NO. K2 AFTER 3 SHOTS, TEST TEMP. $0^{\circ}F$)

FIGURE 15 ES TI-B-REM-V-TREATED STEEL EXPLOSION BULGE SPECIMEN



TENSION SIDE



COMPRESSION SIDE

(NO. K3 AFTER 1 SHOT, TEST TEMP. 0°F)

FIGURE 16 ES TI-B-REM-V-TREATED STEEL EXPLOSION BULGE SPECIMEN

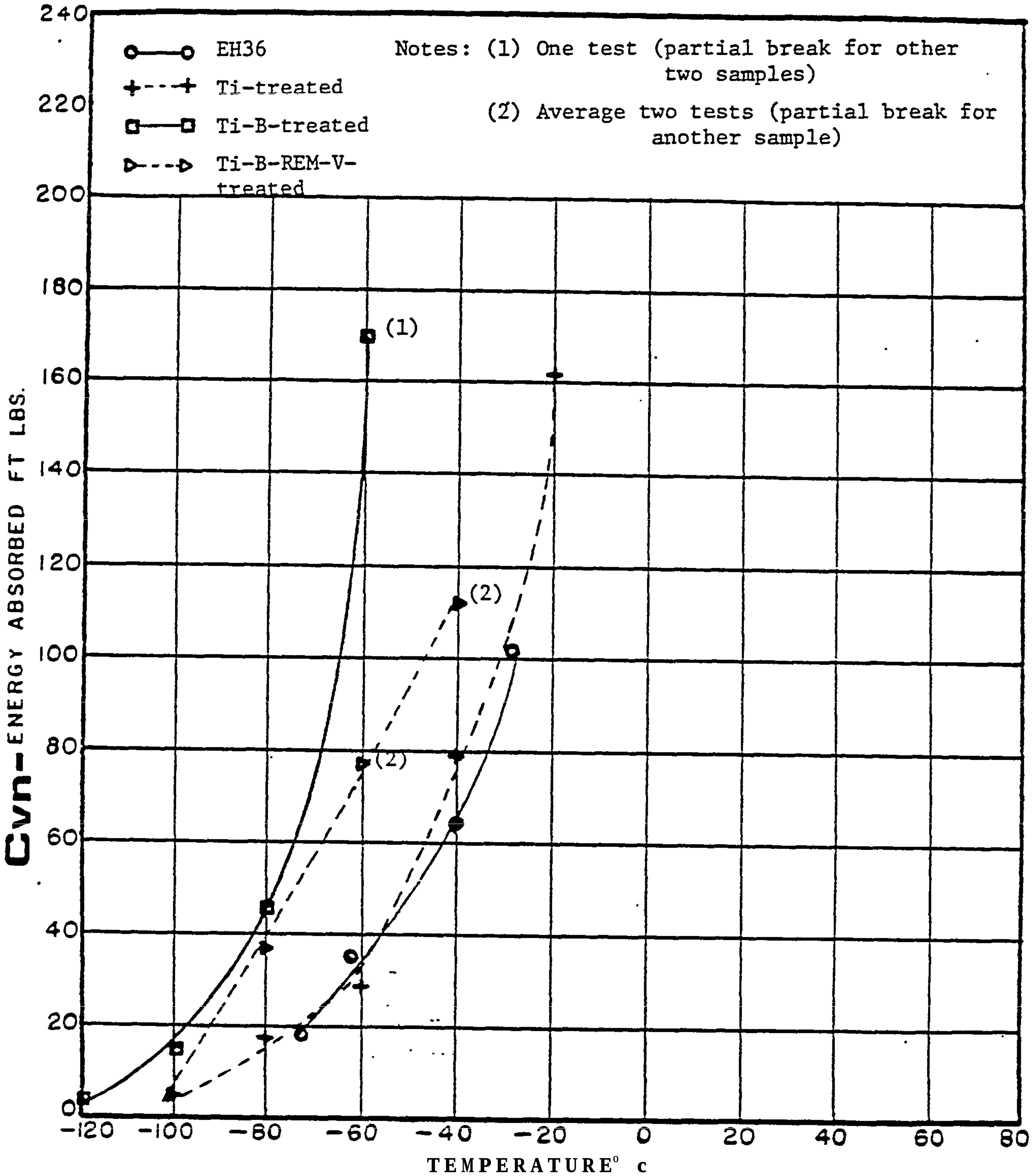


FIGURE 17 CVN IMPACT ENERGY OF BASEMETALS

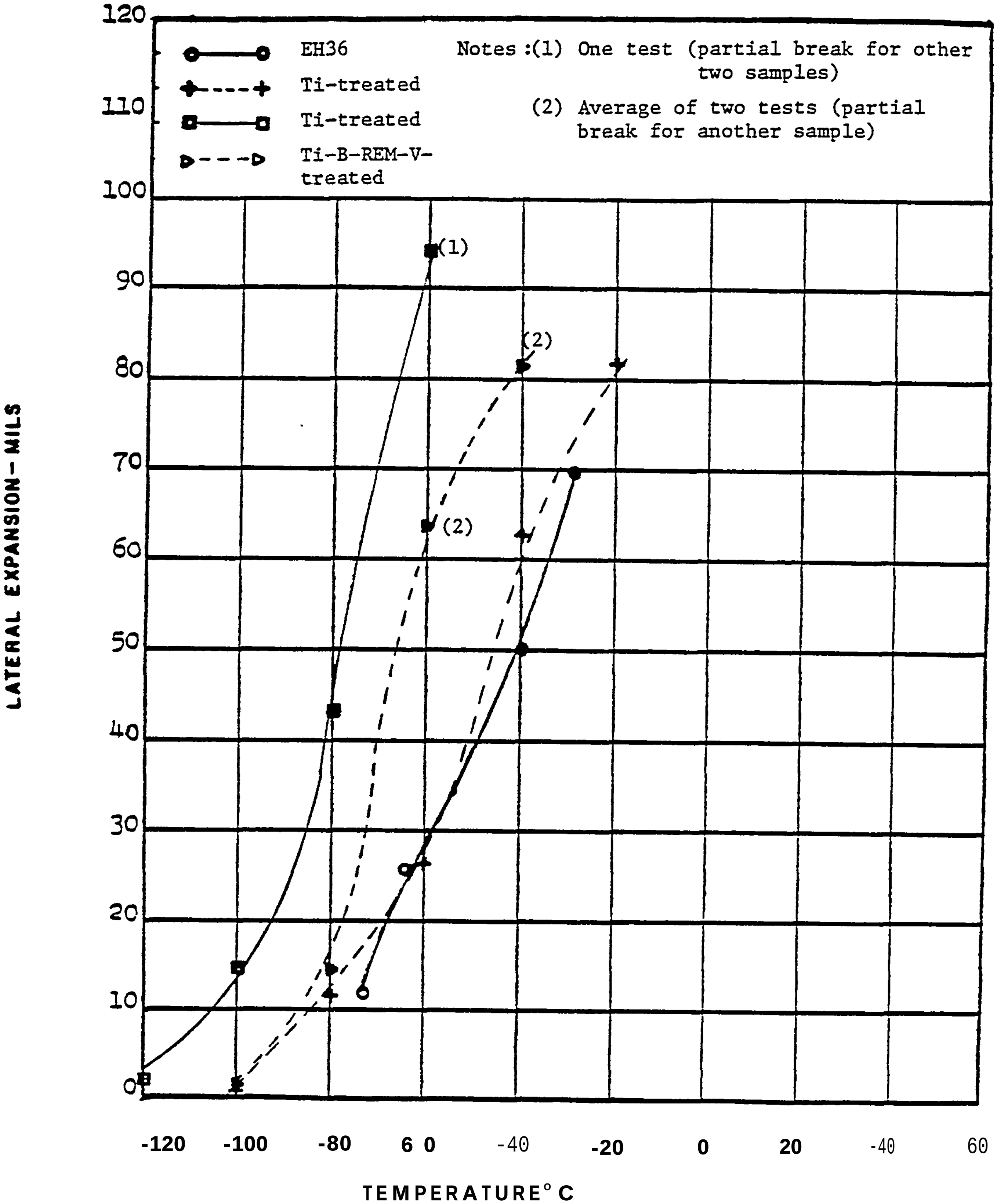


FIGURE 18 LATERAL EXPANSION OF BASE METALS

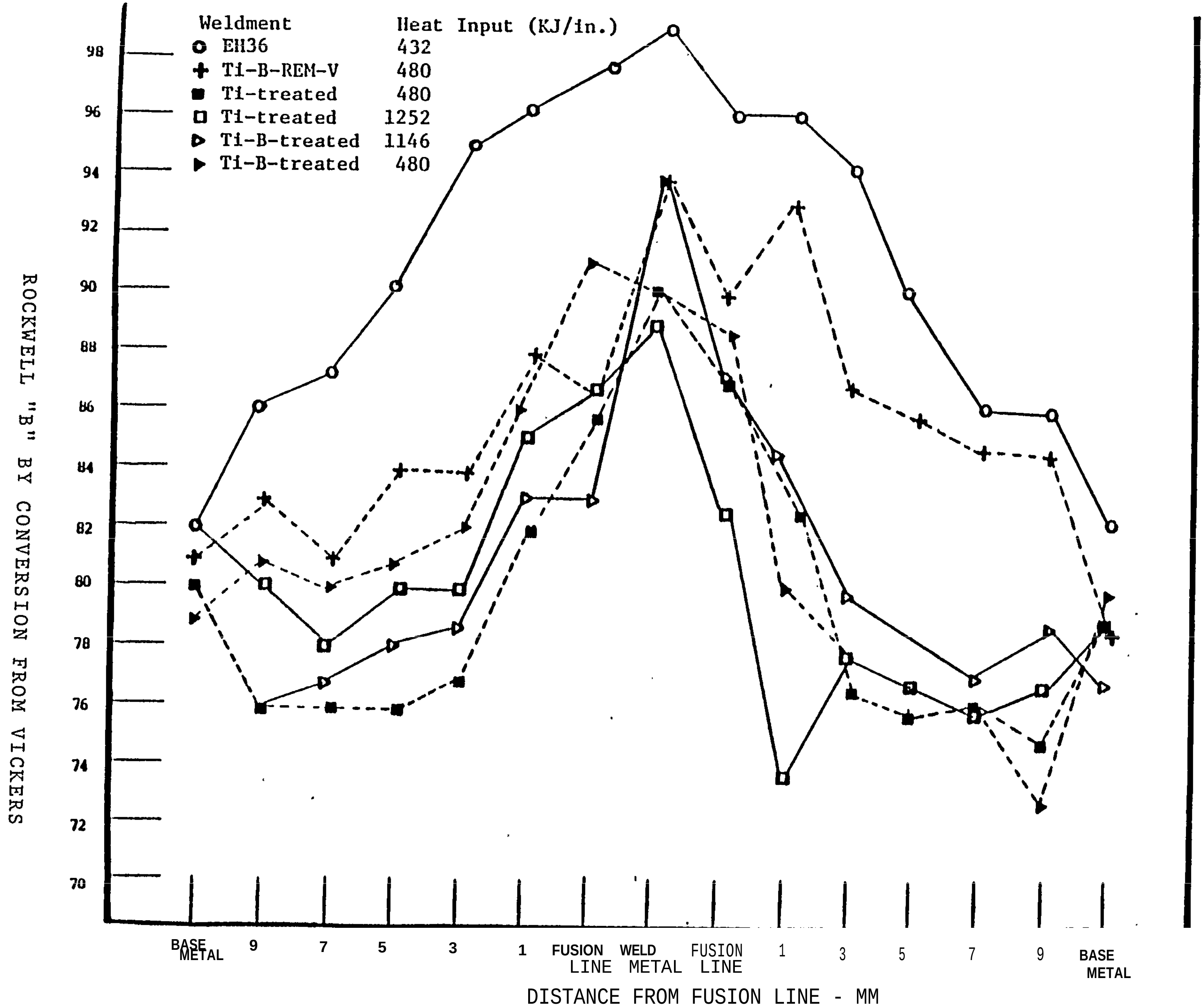


FIGURE 19 HARDNESS TRAVERSE ACROSS WELDS

PANEL SP-8

INDUSTRIAL ENGINEERING

J.R. Phillips
Bath Iron Works

Chairman

ANALYTICAL EDUCATION: A KEY TO IMPLEMENTING ADVANCED SHIPBUILDING TECHNOLOGY

The National Shipbuilding Research Council's Committee on Navy Shipbuilding Technology identified this as an important issue.

> "Engineers and managers play a key role in productivity innovation by making decisions to innovate and then planning and committing the organization to implementation. The more sophisticated the engineers and managers, the more likely they are to understand the direct links between their skills and productivity.
>
> Many shipyard engineers and managers have worked their way up through the skilled trades. Such employees are likely to have intimate knowledge of that shipyard's practices and procedures, but only limited familiarity with broader engineering and management principles. That kind of background also may not be the best for overseeing the introduction of new technologies."[1]

U.S. Shipyards Uncompetitive

We constantly hear the phrase, "the Competitive Challenge" with respect to overseas shipyards. The market for building commercial ships in the United States has disappeared except for a very few needed to satisfy the Jones Act. The "Competitive Challenge" is no myth, but rather a well-documented fact. American shipyards do not build ships as economically or efficiently as either the Europeans or the Japanese. With U.S. prices for tankers 90% higher than in Europe and two to three times higher than the Far East,[2] it is no wonder that few new contracts are going to U.S. shipyards.

A Depressed Market

The situation is further compounded by the lack of new orders world-wide. The intensifying competition between Far East shipbuilders only makes matters worse for the U.S. Predictions discussed in current literature are consistently expecting the shipbuilding recession to extend through the 1990's. Inevitably there will be casualties both here and abroad. There is simply too much shipbuilding capacity to be supported by the meager demand. In a recent issue of the Marine Engineering/Log, the editor points out:

> "The world's shipyards have run out of miracles ... even in the Far East. The year opened with the four major Korean builders receiving not one solitary new building order in January. In the initial phase of first quarter of the current year, export orders on Japanese yards fell to the lowest level ever. Indeed, the first quarter of 1985 'will surely pass into history as one of the bleakest periods ever for salesmen in the international shipbuilding industry,.' in the view of Oslo broker R. S. Platou, A.S."[3]

> "Shipyards will have to close. The Shipbuilders Association of Japan, and other leading authorities feel that market forces will facilitate a "natural selection" that will dictate who the losers will be. The surviving companies will inherit a leaner, fitter industry with a "hi-tech" base."[4]

What About Us

Considering the depressed shipbuilding market and our uncompetitive position, does the U.S. shipbuilding industry have a future?

The answer is a very positive yes! There will be more shipyard closures, but by and large a stronger and more dynamic industry will emerge.

In the short term, the *Navy* buildup will provide the necessary work to maintain a core of viable shipyards. Beyond that, each yard remaining must be fully committed to implementing advanced shipbuilding methods and technology if they hope to secure new commercial work.

Technology Transfer

Since the mid-1960's, when the Japanese shipbuilders captured the lion's share of the commercial shipbuilding market, many industry experts advised U.S. shipyards *to* adopt Japanese shipbuilding methodologies which included:

1. "Careful analysis of vessel as to size blocks and shape with refined drawings or sketches of each weldment, together with machinery, piping, etc. to be installed at assembly shop or area.
2. Coordinated material control.
3. Allocation of labor and time schedule for each operation.
4. Installed machinery, piping and other equipment to a great extent before erection.

5. Reduced staging to a minimum.

6. Introduced inorganic-zinc coating in the assembly line.

7. The key to rapid construction is how to weld without distortion and shape or weldments or modules that defy or resist distortion especially when such affects the vessel's measurements and locked-in stresses."[5]

In the past twenty years, aggressive U.S. shipyards have made great strides 'toward closing the competitive gap. They have sent representatives to Japanese yards to get first-hand observations of the methodologies in use there as well as bringing consultants from Japan to accelerate the transition to modern zone-oriented methods.

Technology Transfer Uncovers a Problem

Soon after the technology transfer began in earnest, it became evident that the transfer of ideas and methods was not enough. Managers of the U.S. shipyards were attempting to implement modern technology while maintaining their old style decision-making processes. There has been and still is a serious shortage of analytically trained personnel in shipyards. In the words of Prof. Hisashi Shinto, retired president- of Ishikawajima-Harima Heavy Industries Co., Ltd., "Only America can surpass Japan in shipbuilding. But, we do not worry because America has a human problem, not enough college educated people in middle management."

Why is analytical training so important? The following excerpt from a' paper given in testimony during a 20 *June* 1984 hearing by the House Merchant Marine Subcommittee helps to answer this question.

"All say that we cannot ignore the need for more educated managers. The singular difference between a traditional up-from-the-trade shop manager, and a shop manager educated to think analytically about the systematic nature of manufacturing is ability to analyze any influence for its impact on an entire manufacturing system.

Insufficient analysis by current middle management is already manifest in a way that threatens to slow shipbuilding technology development in the United States. Where the refined technology from Japan is now being applied, some traditionally educated American managers feel that they have already perfected the "new methods" and are now introducing some innovations that would be of interest even to the Japanese. However, most are still preoccupied with parochial concerns and are not yet talking about contributions for constantly improving an entire shipbuilding system."[6]

Analytical thinkers are constantly gathering data, identifying trends and promoting improved productivity. Accurate feedback describing how systems are performing is critical to the decision-making process and can only be supplied by statistical methods carried out by shop managers, supervisors and workers. Dr. W. Edwards Deming, a consultant in statistical studies who is renowned for his work in Japan which created a revolution in quality and in methods of administration, insists that educational efforts must cover the whole company.

The SPC Helping to Meet the Challenge

The Ship Production Committee (SPC), under the auspices of the Society of Naval Architects and Marine Engineers (SNAME), was established to identify ways of improving productivity and helping U.S. shipyards meet the competitive challenge from foreign shipbuilders. The SPC consists of eleven technical and research panels that cover the whole spectrum of shipbuilding. Funding for this work comes jointly from the U.S. Maritime Administration, the U.S. Navy, and from private industry. In recent years, the SPC panels have funneled the bulk of their limited resources toward implementing advanced technology in shipyards and identifying the educational needs of shipyard personnel.

Panel SP-8 on Industrial Engineering is one of those eleven SPC panels. The role of SNAME Panel SP-8 is to raise the awareness of shipyard decision-makers to the benefits of scientific management and to promote the use of an analytical approach to problem solving in shipbuilding. This is done through the effective use of industrial engineering techniques to assist in the selection of advanced shipbuilding technologies most appropriate to a given yard, and to later assist in the implementation of results-oriented projects.

From its birth in 1978, Panel SP-8 worked primarily to develop labor standards and identify new technologies. In the early 1980's. SP-8's panel members began shifting their attention to the problem of implementing advanced shipbuilding technology and the issue of formal analytical education. They recognized the impact that highly trained Industrial Engineers (I.E. 's) were having in other industries. They felt that the 'I.E. expertise was needed in shipyards to fully utilize the new technologies. The National Research Council's Committee on Navy Shipbuilding Technology recentlly reconfirmed this as an important issue.

> Engineers and managers play a key role in productivity innovation by making decisions to innovate and then planning and committing the organization to implementation. The more sophisticated the engineers and managers, the more likely they are to understand the direct links-between their skills and productivity.[7]

<u>But Why Industrial Engineers?</u>

As defined by the Institute of Industrial Engineers, the profession of industrial engineering involves the design, improvement, and installation of integrated systems of people, materials and equipment. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design in order to specify, predict, and evaluate the results to be obtained from such systems.

Although industrial engineering schools teach their degree students an analytical, integrated-systems approach to setting and achieving company goals, shipyards generally are not taking full advantage of this training. Few-commercial shipyards even employ people with actual industrial engineering degrees.

The industrial engineer, like other specialists, can function best as part of a management structure which promotes teamwork. Coordination of efforts among the designers, builders, facilities maintenance, and support groups is critical to achieving the best overall results. Properly assigned, industrial engineers can help a shipyard to select and implement appropriate new techniques, while at the same time making a better profit on the vessels presently under contract.

<u>SNAME Panel SP-8 Programs</u>

Panel sponsored projects are now aimed at increasing the role of industrial engineers and use of industrial engineering techniques in shipyards. The first of these, entitled, "Industrial Engineering Curriculum for Use in Shipyards," was co-sponsored by Panel SP-9 on Education. That effort produced a matrix of shipyard problems and situations to which the most effective industrial engineering techniques are being, or can be, applied. From that matrix evolved a curriculum ranking those techniques and listing sources of educational materials and training courses related to them.

That effort set the stage for a Fiscal Year 1984 project entitled, "Shipyard Training Packages for Industrial Engineering Procedures." The technical objective of this effort is to develop shipyard oriented training materials that will address the theory and practice of basic industrial engineering techniques identified in the curriculum discussed earlier. These materials can be integrated into existing employee training programs and college level courses of instruction to improve employee performance and stimulate interest for a career in the U.S. shipbuilding industry.

To further demonstrate Panel SP-8's commitment to increased training in basic industrial engineering techniques, it is sponsoring a series of workshops on methods engineering for the shipbuilding industry. The workshops, conducted by the Institute of Industrial Engineers, are an outgrowth of a five-day pilot workshop held in Atlanta in 1981. They are designed to train and instruct shipyard managers and personnel in the techniques of methods engineering in shipbuilding. Workshops are scheduled to be held in late September, 1985 at four sites around the country. There will be no charge for attending these workshops.

Greater management awareness of industrial engineering techniques and the more effective use of these techniques by personnel responsible for the implementation of new technologies will ensure smooth and rapid integration of these technologies into existing organizational structures. To facilitate this awareness, a project entitled, "Optimal Use of Industrial Engineering Techniques in Shipyards" proposes to produce a comprehensive report concerning the analytical procedures available to shipyards through increased recognition and use of industrial engineering techniques. This project will specifically address ways in which these procedures may be used to support the implementation of advanced shipbuilding techniques such as Group Technology, Product Work Breakdown Structure, Flexible Manufacturing, and 'Accuracy Control. Recommendations on organizational relationships between and I.E. department and other functional departments will also be made.

Additionally, FY-85 plans include a follow-on effort to develop additional training packages for industrial engineering procedures. Also, a materials handling and facilities layout training module will be developed. Finally, phase one of a two-phase effort to identify the impact of workload variability will get underway. These projects are further proof that Panel SP-8 is deeply committed to the educational and training needs of U.S. shipbuilders.

In Conclusion

Not only U.S. shipyards, but shipyards worldwide, are feeling the impact of declining new construction orders. As the shipbuilding depression continues, it is forcing all yards to become as efficient as possible if they intend to stay in business, Many shipyards will close, but those that remain will have had to make significant changes in their ways of building ships. Industry analysts agree that how well shipyards implement advanced shipbuilding technology will determine their success or failure.

Industrial engineers can help maximize the benefits of these advanced techniques. The analytical skills they bring to the industry will help provide the data feedback needed for full implementation. Where industrial engineers are not available, the alternative is to train shipyard personnel in industrial engineering techniques. Such training needs to be focused to specific needs in order to fill the educational void as rapidly and economically as possible.

SNAME Panel SP-8 recognizes the void exists and is working to fill it. SP-8 is sponsoring programs that range from identifying how industrial engineering techniques can best be used in shipyards, to developing training materials for self training, to actually providing methods engineering workshops. These programs will do much to close the competitive gap; but ultimate success depends on the total commitment of U.S. shipbuilders to such programs.

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COMPUTERIZED APPLICATION OF STANDARDS

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Newport News Shipbuilding

ABSTRACT

A computer program has been developed which provided for the elimination of manual applications of standards by integrating previously developed standards into existing computer-aided design systems. Standards for the pipe shop were developed between 1978 and 1979 using Manual MOST (Maynard Operation Sequence Technique). Since 1979, these standards, along with information obtained from existing production computer systems have been used by engineering Personnel to manually apply standards to pipe shop work packages which are part of a production control system used to schedule and track the progress of pipe details through each shop work center.

The Computer Center, Industrial Engineering, and Production Engineering worked together to develop a computer program to apply standards to the pipe detail work packages for operations in the pipe shop. Prior to the program's development, the existing manual application system, including computer-aided design drawings and manual standards application matrices were reviewed. Next, the link between the existing computer system and manual application process was established by standardizing the input data through the development of type codes. The development of the computer program emphasized the application of standards to the bending, fabricating, welding, and machining operations in the pipe shop.

The implementation of this program into the computer-aided design system has resulted in improved accuracy and consistency of standards application. Other benefits resulting from the computerized application of standards include: increased manhour productivity, standardization of pipe detail part terms; capability to apply detailed standards, and the capability for computerized transfer to the Production Scheduling and Control System.

The opinions presented in the Paper are those of the authors and do not necessarily reflect those of Newport Mews Shipbuilding and Dry Dock Company.

EXECUTIVE SUMMARY

The computerized application of standards project successfully proved that previously developed standards could be applied by an existing computer-aided design system to eliminate manual application of standards. At Newport News Shipbuilding, the Computer Center, Industrial Engineering, and Production Engineering at Newport News Shipbuilding worked together to develop a computer program to apply standards to the pipe detail work packages for the bending, fabricating, welding, and machining operations in the pipe shop.

The implementation of this program into the computer-aided pipe detail design systems has resulted in improved accuracy and consistency of standards applications. Other benefits resulting from computerized application of standards include: increased manhour productivity, standardization of pipe detail part terms, and capability to apply detailed standards.

The development of the program took approximately eight months and involved extensive communications between the computer programmer and the Production Engineering pipe shop planners. This level of effort was based on the existence of a computer-aided pipe design system generating pipe detail work packages and a well-established manual standards application system. Although the transferability of the program software may be minimal, the approach and techniques used to develop the program should be highly transferable.

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INTRODUCTION

Traditionally the application of standard times to specific operations in work packages has been a manual process. However, the increasing use of computer-aided design systems in the development of work packages lends itself to the computerized application of standard times. This concept is the basis for a project performed by Newport News Shipbuilding and funded by the Maritime Administration Ship Production Panel on Industrial Engineering (SP-8).

By January 1985, Newport News Shipbuilding had successfully implemented a project to develop a computerized standards application program. This program utilizes standards that were previously developed by Maynard Operation Sequence Technique (MOST) and existing computer-aided design (CAD) systems to eliminate the manual application of standards. This paper will describe the development of the computer program and the results obtained from its implementation.

There were three key elements essential to the successful implementation of the computerized standards application program:

- previously developed standards
- existing computer-aided design system
- a well established manual standards application system

At Newport News Shipbuilding, the area of standards

application best meeting these criteria was the yard's pipe shop operations. The pipe shop had a well established work package system that utilized manually applied standards as part of a production scheduling and control system. This work package system was supported by a CAD system which generated pipe details with the pipe manufacturing data required for standards application.

Having; these elements in place enabled the effort on this project to be focused on development of the interface program and not on data or standards development. To promote a better understanding of the program, background information on the piping CAD system, MOST time standards, pipe shop work packages, and standards application will be provided. This will he followed by an overview of-the program development and a description of the program content. Results and benefits derived by Newport News Shipbuilding as a result of the implementation of this program will be provided at the end of this paper. For an in-depth review of the program, an appendix is provided that includes a detailed flowchart of the program and a step-by-step explanation of 'the flowchart.

BACKGROUND

One of the early objectives of the SP-8 Panel was to demonstrate the benefits of standards development and application in selected areas of shipbuilding.. Various methods of developing standards were considered hut the amount of time for the average shipbuilding_ work process is so long that traditional work measurement systems (such as MTM) are not appropriate. Stopwatch time studies are time consuming and not very effective since shipbuilding does not tend to be a repetitive, assembly line type operation. The system chosen to establish the standards was Maynard Operation Sequence Technique (MOST). MOST is a pre-determined work measurement system that concentrates on the movement of objects. It is a fast, accurate technique that is methods conscious and easy to learn and apply. For these reasons, as well as its adaptability to shipbuilding processes, MOST was selected for standards development.

In support of this objective, Newport News Shipbuilding had projects authorized in the early 1980's to develop and apply MOST standards. Having completed these projects, interest at Newport News was directed toward two areas: reducing the repetitive costs associated with standards application and reducing the manpower burden of standards application, thereby allowing more resources to he directed toward planning and standards development. To address this need, Newport News Shipbuilding proposed a project to develop a computerized pipe standards application program. This was a timely project for SP-

8 since it provided a means of using Newport News Shipbuilding's greater experience in MOST standards application to expand the panel's activity beyond standards development and manual application of standards. This project would also act as a guide for the standards effort in other shipyards participating in the panel. In November 1983 funding was provided to Newport News Shipbuilding for a twelve month project to develop a program for computerized application of pipe standards.

The pipe shop standards application process was selected for this project because the shop had a well established pipe work package system utilizing manual application of standards. The pipe shop standards had been developed between 1978 and 1979 using MOST. During this development major emphasis was-placed on minimizing the complexity and time required to manually apply standards. To this end, standards were categorized and combined into matrices for ease of application by Production Engineering. Since 1979, the standards, along with the information obtained from existing production CAD systems, have been utilized by Production Engineering personnel to manually apply standards to pipe shop work packages for bending, fabrication, welding: and machining operations.

It was anticipated that the computerized application of standards project would provide two benefits: the elimination of manual application of standards to the pipe shop work packages at Newport News Shipbuilding and an example for other yards to follow when making the transition from manual standards

application to computerized standards application.

APPROACH

To accomplish this project in the time allotted, it was recognized that personnel well qualified in the areas of standards application, work packages, and CAD systems must be assigned to the task. Three departments were identified to work on this project:

- Industrial Engineering

  To provide their expertise in standards development and application, and to provide project management and control.

- Production Engineering

  To provide their knowledge of work packages and production control systems, and to perform the implementation, testing and acceptance of the program.

- Computer Center

  To provide a programmer/analyst to develop the computer program.

Newport News Shipbuilding was fortunate to have highly skilled, quality personnel to assign to this project, particularly the computer programmer who had been responsible for

the piping CAD system for a number of years. His in depth knowledge-of the piping CAD system, particularly the many yard specific details, proved to be invaluable in the successful development of the program..

Initial contact between these three departments resulted in the establishment of a three phase plan for accomplishing the development of the computer program to interface standards application with the piping CAD system:

- Review existing standards application and CAD systems to develop program parameters
- Program development
- Test and implement program

Each of these phases will be expanded in the following sections.

EXISTING SYSTEM

The existing manual standards application system for the pipe shops involved interfaces between the piping CAD system, Production Engineering and pipe shop foremen. The standards were applied to pipe details by Production Engineering and then organized into work packages for use by the shop foremen.

The pipe details were created from piping design drawings by the piping CAD system. Two documents were generated for each detail: a pipe detail manufacturing record and a working drawing. of the pipe detail. The pipe detail manufacturing record provides the following data:

- how the pipe is bent:
  - number of bends
  - bend radius
  - bend angle

- Layout of pipe detail:
  - distance between centers
  - distance been tangents
  - X, Y, Z coordinates

- how the pipe is fabricated

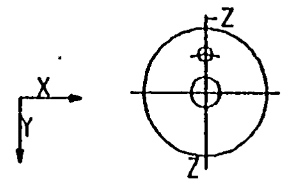
- end preparation required for welding

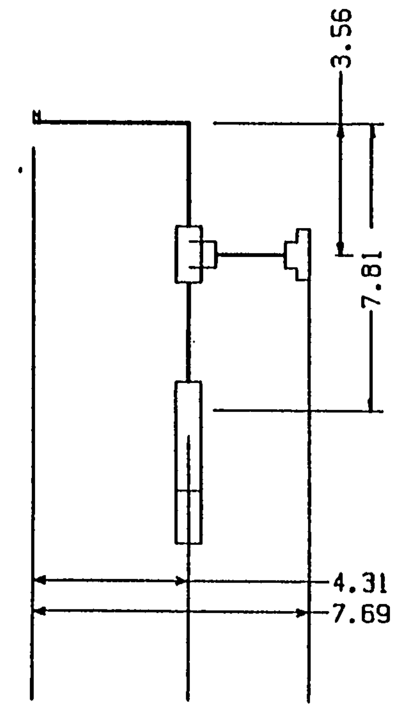
- size and description of pipe and fittings
- material type and part number of pipe and fittings
- miscellaneous fabrication notes

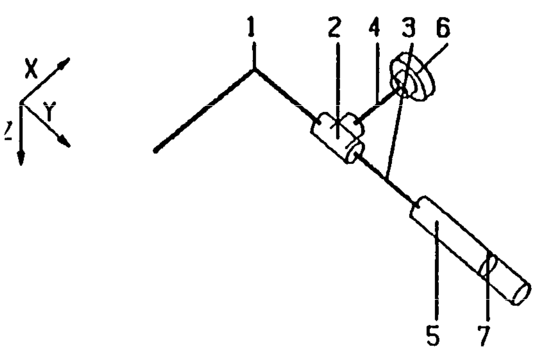
The working drawing (Fig. 1) provides dimensioned views and an isometric sketch of the pipe detail.

After the pipe details were generated by the CAD system, they were sent from the computer center to the Production Engineering shop planners. The standards hours were organized on a pick sheet (Fig. 2) and were used along with the information generated on the pipe detail manufacturing records to manually set the standards for each pipe detail. (It was this step in the process that was computerized by the interface program, allowing the planners more time for pipe shop work package planning.) Work package folders were then established for each pipe detail. Each work package folder included: the pipe detail manufacturing record, the working drawing of the pipe detail, the standard hours for bending, fabrication, welding and machining operations, the parts list, and the material schedule. The material and scheduling information from the pipe detail manufacturing records and the standard times for each work center on each pipe detail were transferred to the production scheduling

ID	PIECE NO	LOCATION	ORIENT	JT TY	JOINT NO.	NOT
1	PI46-1	MAIN PIECE				
2	F2	B END1	90.0-Z	BP		VT
3	P91-1	WITH A F2		BP		VT
4	P91-2	WITH C FZ		BP		VT
5	F18	B HITH P91-I		BP		VT
6	FLI	A WITH P9I-2	IS-Z	BP		VT
7	F5	B WITH A F18	90.0+X	BP		VT







DATE-
SIGNATURE-
LOCATION-

P9I-1

DETAIL	F	PAGE 2	OF 2	
ARR. DWG. NO.	2282 -	299X1		
DET. DWG. NO.	J2282 -	160	REV.	A

Bending

Nominal Pipe Size	Number of Bends 1	2	3	4	5
Applies To All Bending Machines					
1/2" Thru 3 1/2"	1	1	1	1	1
4" Thru 6"	1	1	1	1	1
8" Thru 12" +	1	1	1	1	1

MACHINING
PER PIPE END
1 Man Operation

Nom. Pipe Size	Straight Bevel Operation	Combination J Bevel & Counter Bore
1/2" - 1"	1	--
1 1/2" - 4"	1	1
5" - 8"	1	1
10" - 14"	1	1
15" - 20"	1	1

DRILL HOLES: 1 MHRS/HOLE

WELDING

Joint Dia. or Nom. Pipe Size	Socket Weld: Carbon Steel First Joint	Socket Weld: Carbon Steel Each Add-on	Socket Weld: CUNI, Cres First Joint	Socket Weld: CUNI, Cres Each Add-on	Socket Weld: Chrome-Moly First Joint	Socket Weld: Chrome-Moly Each Add-on	Flange: First Flange	Flange: Each Add-on	Butt Weld: Carbon Steel First Joint	Butt Weld: Carbon Steel Each Add-on	Butt Weld: CUNI, Cres First Joint	Butt Weld: CUNI, Cres Each Add-on	Butt Weld: Chrome-Moly First Joint	Butt Weld: Chrome-Moly Each Add-on	Boss: Each Joint
1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3/4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1 1/4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

FABRICATION

A	B	C	D	E				F		G	H
Pipe or Fitting Diam.	Set-Up The Job	Fittings	Slip on Flange	Special Fittings: Branch	Boss	Weld-o-let	Sleeve	Brazing: Fitting	Flange	Template Set-Up	Assemble Flange To Flange
1/2" Thru 3"	1	1	1	1	1	1	1	1	1	1	1
3 1/2" Thru 5"	1	1	1	1	1	1	1	1	1	1	1
5 1/2" Thru 8"	1	1	1	1	1	1	1	1	1	1	1
8 1/2" Thru 12"	1	1	1	1	1	1	1	1	1	1	1
12 1/2" Thru 16"	1	1	1	1	1	1	1	1	1	1	1
16 1/2" Thru 20"	1	1	1	1	1	1	1	1	1	1	1
20 1/2" Thru 24 1/2"	1	1	1	1	1	1	1	1	1	1	1

Fig 2

and control system by the planners. The work package folders were then sent from the planners to the shop foremen.

PROGRAM DEVELOPMENT

Before a computerized system to apply the standards could he developed, it was necessary to standardize the input data stored by the CAD system. It was discovered that the information on the pipe detail manufacturing record was referenced from a computerized catalog of pipe detail parts. This catalog originally contained the part numbers, descriptions, and material types of all pipe detail parts. For the computer program to apply the correct standards to the pipe detail, it had to be able to use the information in this catalog to accurately identify the parts. However, the information contained in the parts description was not standardized:

- different abbreviations were used for the same part
- the placement of the part name varied in the description field
- many part names were similar (reducer, reducing flange, reducing elbow), therefore not easily identifiable

Without a method of standardizing and cross referencing the pipe detail parts in the catalog to the standards application matrix,

it was not possible to begin development of the application program.

To solve the problem of non-standard data required the cooperation of Production Engineering and the Computer Center. Together they were able to devise a solution that minimized the impact on existing computer records and data input. A coding system was developed that provided the necessary interface between the piping CAD system and the standards application matrices. The type code, which was added to each pipe detail part in the catalog, consists of three letters used to identify the piece type, weld joint type, and additional description of the piece (Fig 3). The type code allows the part to be accurately identified regardless of how it is abbreviated within the description of each pipe detail part. This code was then utilized by the interface program to accurately select the correct standard from the standards matrices.

The development of a type code provided the link between the piping CAD system and standards. application so that the development of the computer program could begin. The program was developed as part of the existing piping CAD system. In this program, standards are automatically applied to each pipe detail as they are developed by the CAD system. The program is divided into four major sections (bending, fabrication, welding, machining) which calculate the standard times for these four pipe shop operations. Each section of the program corresponds to one

EXPLANATION OF TYPE CODES

There are 3 letters to the type code. The first letter identifies the type of piece, and is listed alphabetically. The second letter gives the weld type. Since the weld types do not specifically modify any one piece type, they are listed as a group first. The third letter is used to describe the piece. Since reducing and union are general purpose modifiers, they are listed first.

Piece Type Codes

1st Letter Piece Type	2nd Letter Joint Type	3rd Letter Modifier
A = Adaptor	B = Butt Weld	R = Reducing
B = Boss	F = Flanged	U = Union
C = Coupling	S = Socket Weld	9 = 90° Radius
E = Elbow	T = Threaded	4 = 45° Radius
F = Flange	Z = Sil - Brazed	D = Raised Face
H = Bushing	M = Mixed	O = Slip on
N = Nipple	N = N/A	T = Foundation
P = Pipe		I = Concentric
R = Reducer		E = Eccentric
S = Sleeve		M = Male
T = Tee		w = Female
U = Union		A = Angle
V = Value		B = Ball
w = Weldolet, Sockolet,		C = Check
Brazolet,		G = Gate
X = Cross		L = Globe
Y = Lateral		P = P Trap
Z = Traps		S = S Trap
M = Misc		N = Running Trap
		1 = 1 Node
		2 = 2 Node
		3 = 3 Node

of the standard matrices used in the manual application of standards.

The general flowchart of the computer program (Fig. 4) highlights the areas of standards application:

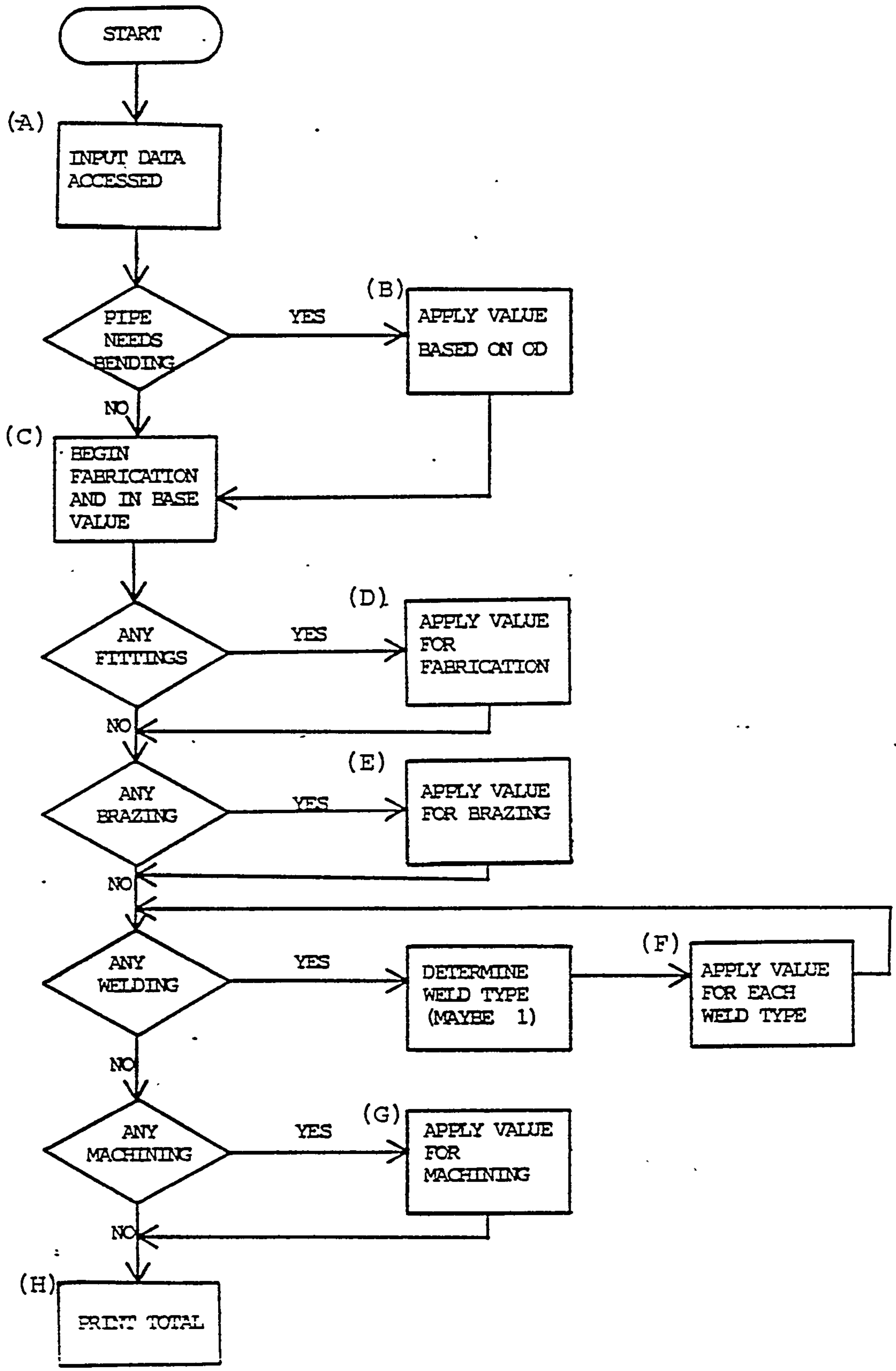
- A pipe detail is selected from the piping CAD system. (A detail maybe a single piece of pipe or may include a main pipe piece with up to 25 fittings.) All data needed to apply the pipe standards is collected from the piping CAD system. (Block A)

- If the pipe requires bending, the pipe diameter and number of bends specified in the input data are used to extract the bending times from the standards matrix. (Block B)

- The base value for the fabrication set up times are applied. (Block C)

- If fittings are included as part of the detail, the piece diameter and type of fitting specified in the input data are used to extract the fabrication values for each fitting. (Block D)

- If brazing is required, the piece diameter and type of fitting specified in the input data are used to



START
(A)
INPUT DATA ACCESSED
PIPE NEEDS BENDING
YES
(B)
APPLY VALUE BASED ON OD
NO
(C)
BEGIN FABRICATION AND IN BASE VALUE
ANY FITTINGS
YES
(D)
APPLY VALUE FOR FABRICATION
NO
ANY BRAZING
YES
(E)
APPLY VALUE FOR BRAZING
NO
ANY WELDING
YES
DETERMINE WELD TYPE (MAYBE 1)
(F)
APPLY VALUE FOR EACH WELD TYPE
NO
ANY MACHINING
YES
(G)
APPLY VALUE FOR MACHINING
NO
(H)
PRINT TOTAL

extract the brazing time from the fabrication standards matrix. (Block E)

- If welding is required, the type of weld (butt weld or socket weld) is determined and the piece diameter, material type, and joint description specified in the input data are used to extract the weldine. time. (Block F)

- If machining is required, the type of bevel and pipe diameter specified in the input data are used to extract the machining time. (Block G)

- The standard time values for each operation are printed out and included with the piping CAD documents. These documents are delivered to the planners to be used when developing the pipe shop work packages. (block H)

A detailed flowchart of the program and explanation of the flowchart are included in the Appendix.

TESTING AND IMPLEMENTATION

After the development of the standards application program was completed, the program was tested for completeness

anti accuracy. Testing was accomplished by comparing the standard time results from the program with those applied manually by the planners. Initial tests resulted in requirements for only minor modifications to the program. Once these modifications had been made, the comparisons between standards application continued: A cross section of pipe details were tested in this manner until the results were consistently correct.

When the computer applied standards were compared to the manually applied standards, the computer application proved more accurate in many cases than manual application. An added benefit is that the program will not attempt to calculate the standards with incorrect input data. A data error message is printed with the pipe detail so the data corrections can he made. Generally these types of errors were overlooked during manual standards application.

After the testing was complete, the program was put into production use. A follow-up review of the production system has shown the application of the program to be very successful.

BENEFITS

This project successfully proved that MOST developed standards could be applied by an existing computer-aided design system to eliminate the manual application of standards. Computerized application of standards has resulted in improved:

- accuracy

- consistency
- productivity

Preliminary results indicate that the costs, excluding program development, for computerized application are approximately equal to the costs for manual application. There are several reasons why both application processes appear to result in equal costs.

- The standards application pick sheets were designed for ease of manual application. The detail of the standards were compromised so they could he categorized for easier application.

- The planners are-organized into specialized groups according to the standards application pick sheets. Therefore, over a period of time, each planner becomes highly skilled and proficient in standards application within his areas.

- The computerized application processing costs are temporarily high since this program was written to be compatable with a new computer system and not most efficient under the existing system. A system changeover is occurring which will reduce processing costs.

Benefits resulting from the computerized application of standards include:

- Increased manhour productivity
  The manual application of standards has been eliminated resulting in additional time for the planners other work. Computer costs do not directly correspond to manhour costs.

- Improved accuracy and consistency
  The computer is not prone to fatigue and mistakes present in manual application.

- Standardization of pipe detail part terms
  The capabilities of the existing computer-aided pipe detail manufacturing system is expanded by being able to accurately identify parts.

- Capability to apply detailed standards
  The standards are currently used as targets by the pipe shops. If more detailed standards were required, the matrices on the application pick sheets would be expanded, making it difficult for manual application but having little or no impact on computerized application.

CONCLUSIONS

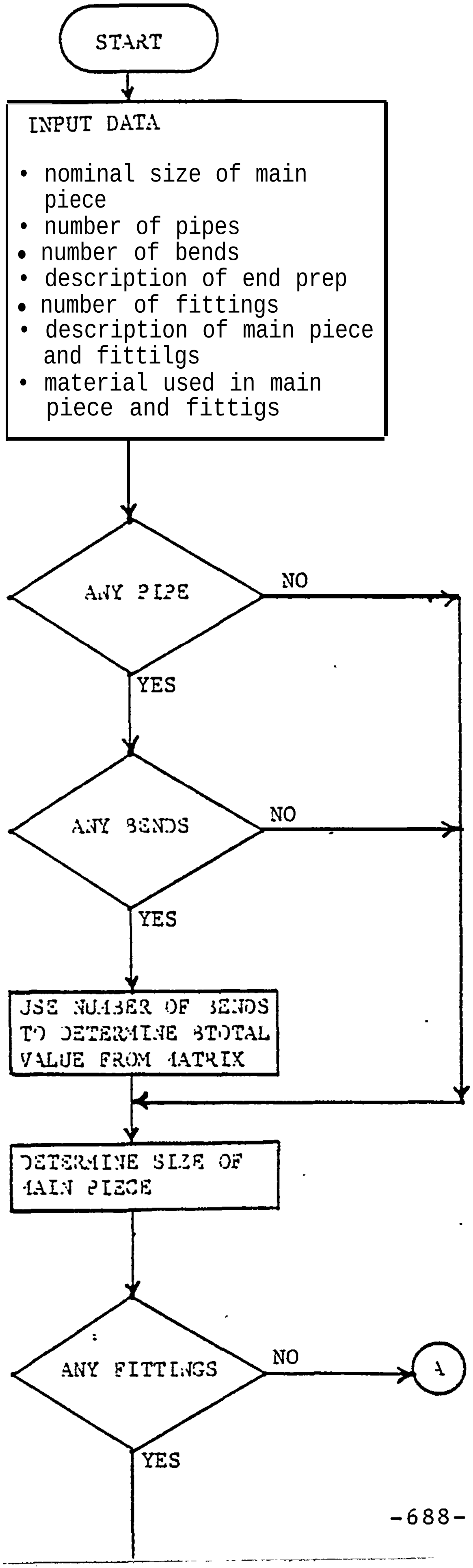
This project successfully proved that previously developed standards could be applied by an existing computer-aided design system to eliminate manual application of standards. Computerized application of standards proved superior to manual application and particularly beneficial if concerned with accuracy, consistency, and application of detailed standards.

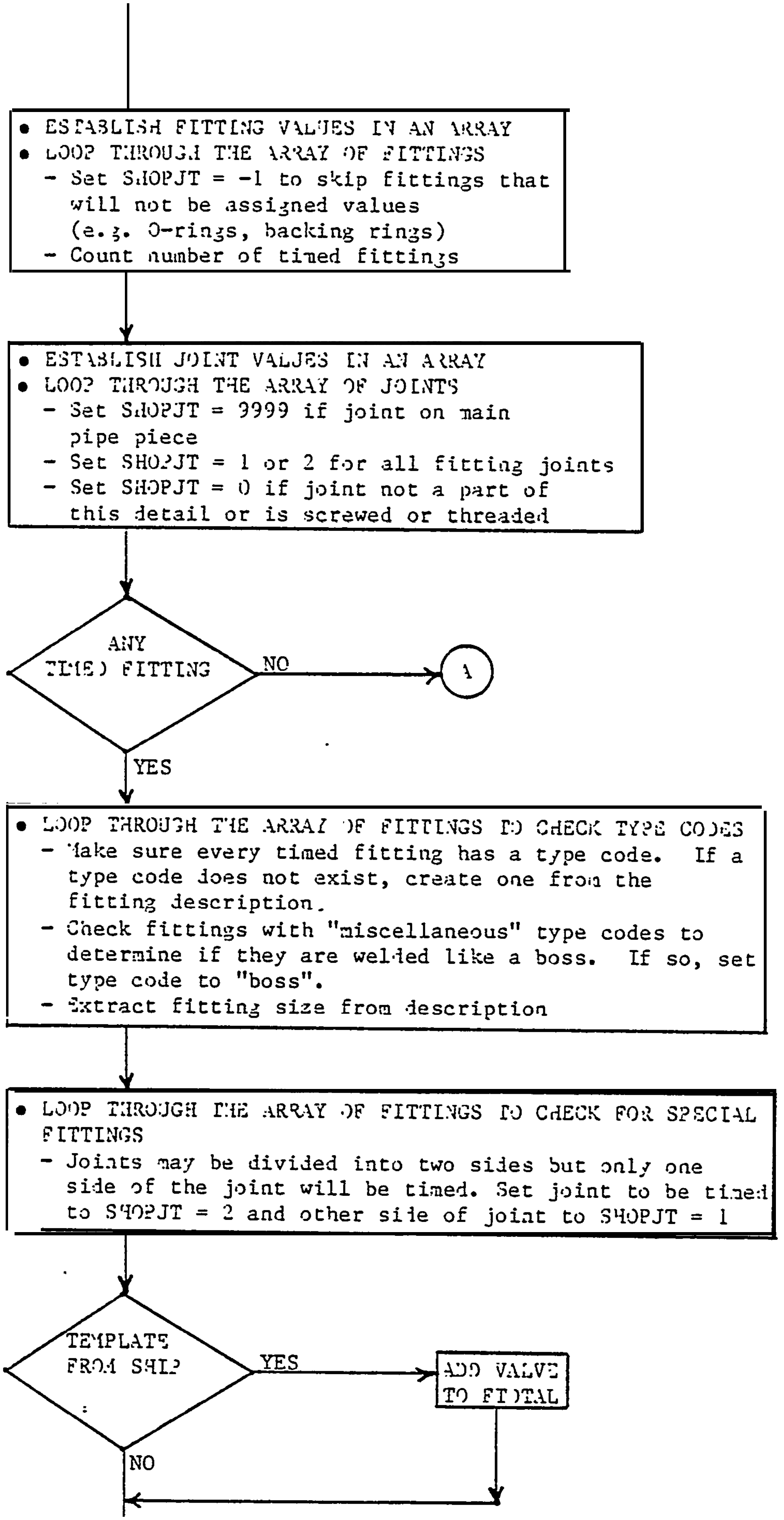
The transferability of this program depends on the computer-aided design systems and standards application processes in use. Due to the company-oriented nature of these systems and processes, the transferability of the actual program software is probable minimal. However, the approach and techniques used to develop this program should-be highly transferable. This information should reduce the time and effort required to develop the program. However, before a project of this type is undertaken, good in-house knowledge of standards, standards application, CAD systems, and their uniqueness to a specific shipyard should be assured.

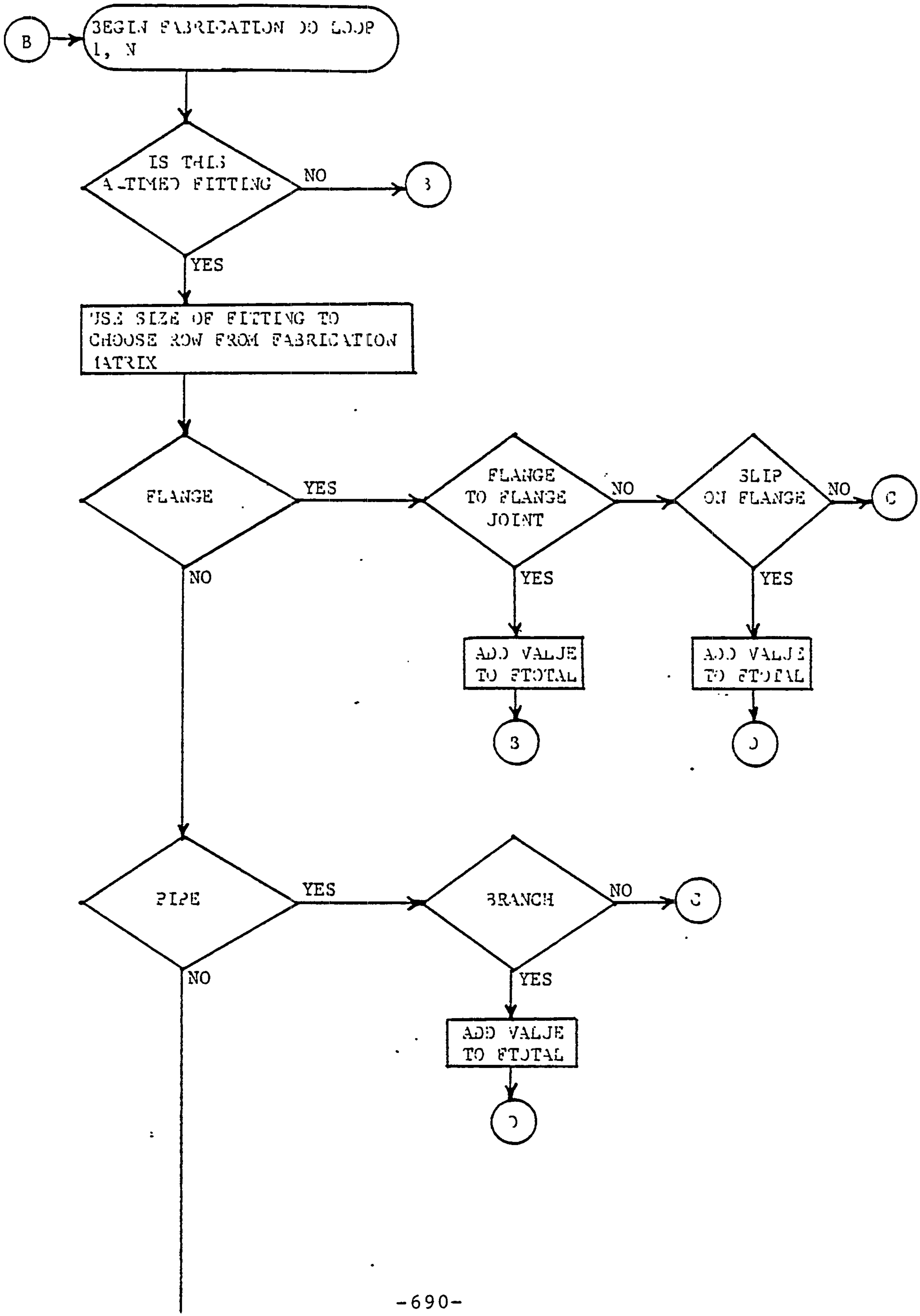
APPENDICES

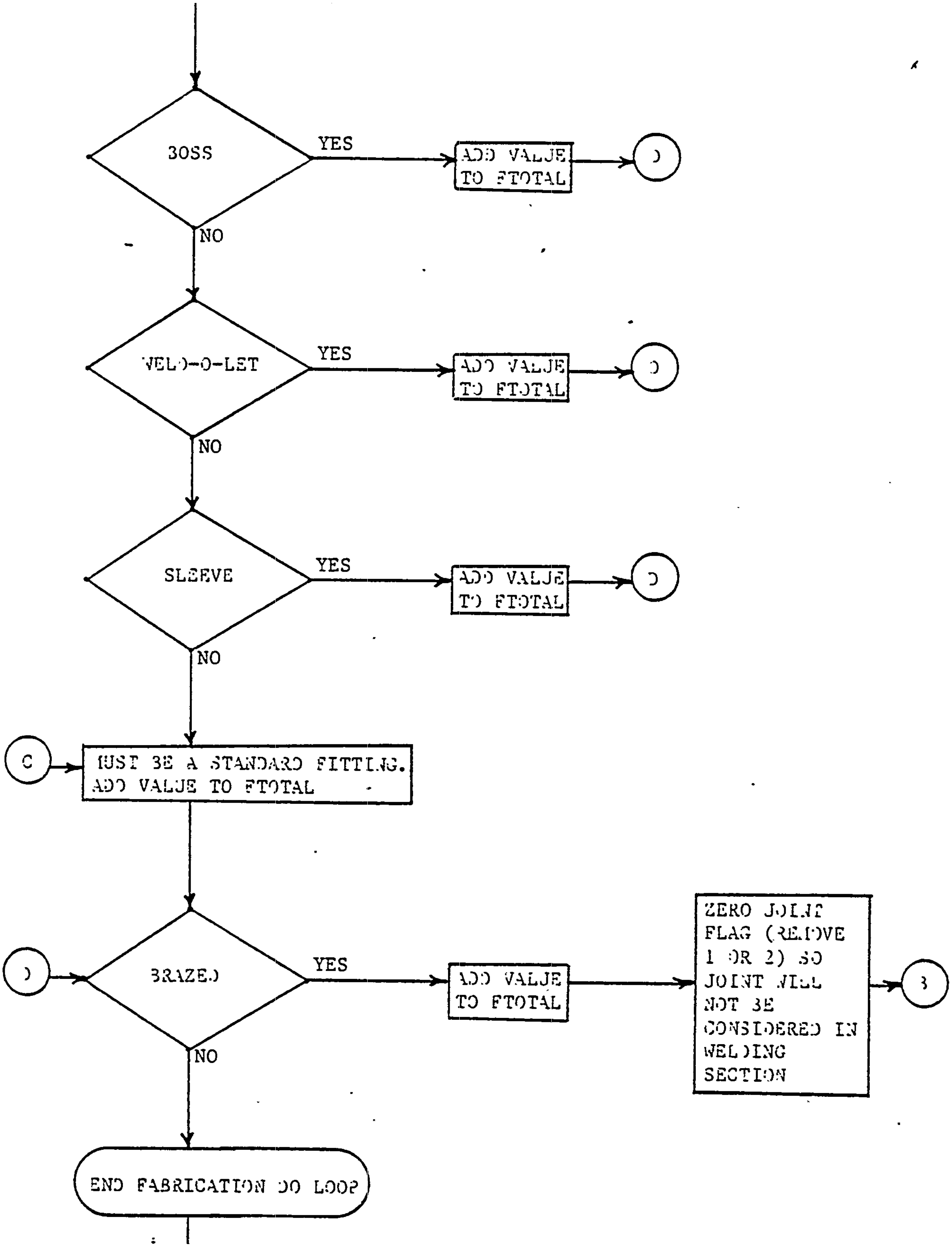
APPENDIX A

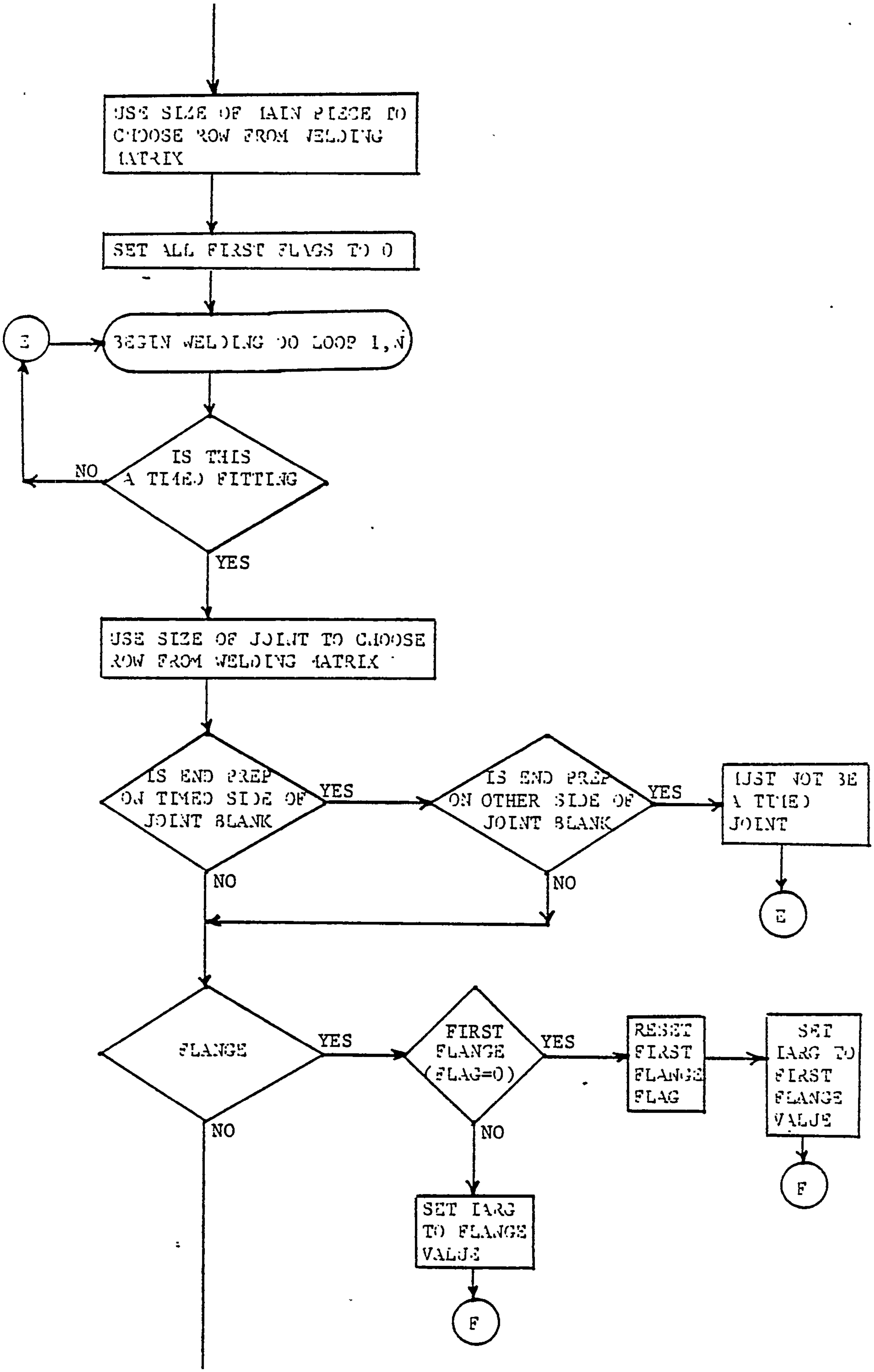
Detailed Flowchart

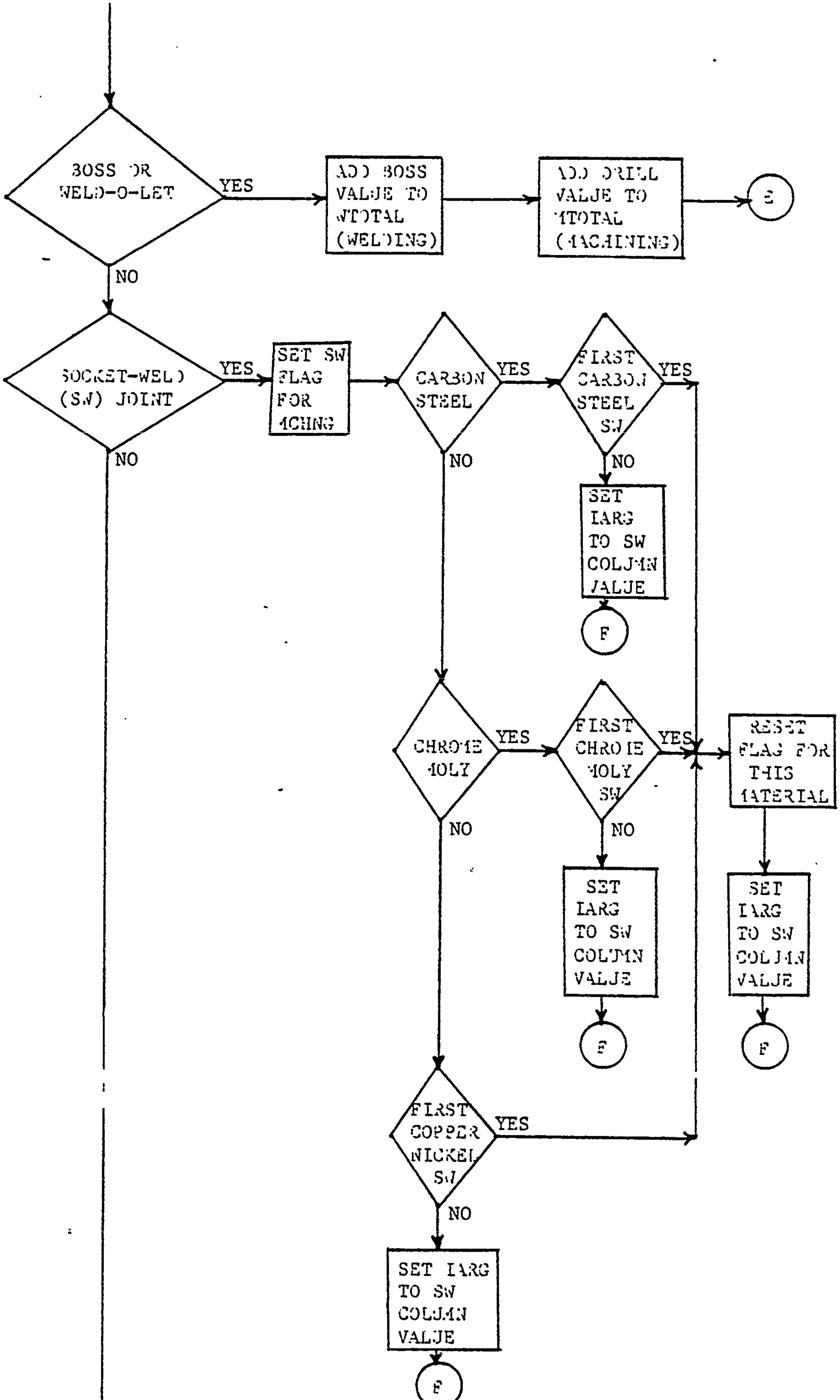

START
INPUT DATA
• nominal size of main piece
• number of pipes
• number of bends
• description of end prep
• number of fittings
• description of main piece and fittilgs
• material used in main piece and fittigs
ANY PIPE
NO
YES
ANY BENDS
NO
YES
USE NUMBER OF BENDS TO DETERMINE BTOTAL VALUE FROM MATRIX
DETERMINE SIZE OF MAIN PIECE
ANY FITTINGS
NO
A
YES

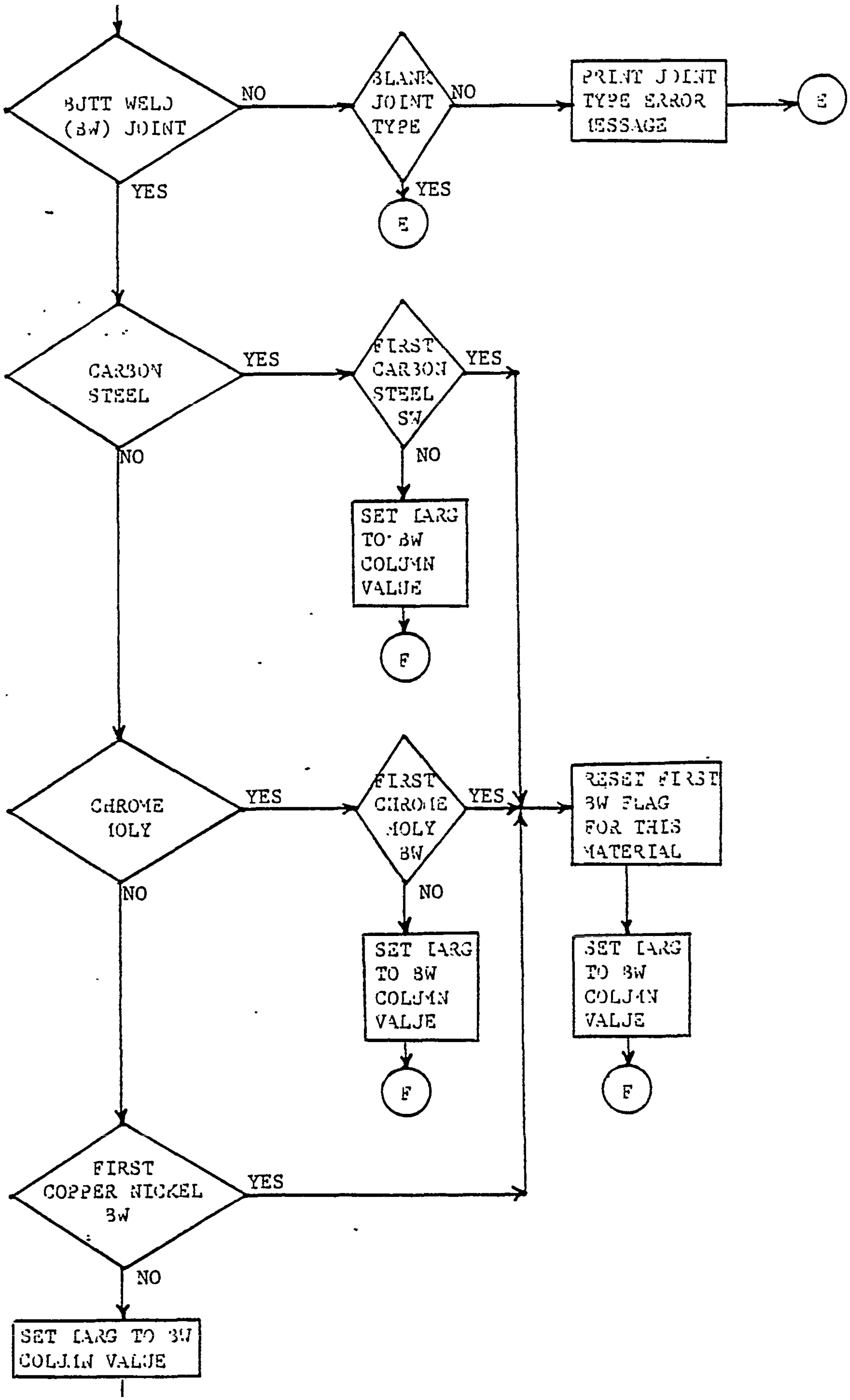

• ESTABLISH FITTING VALUES IN AN ARRAY
• LOOP THROUGH THE ARRAY OF FITTINGS
- Set SHOPJT = -1 to skip fittings that will not be assigned values (e.g. O-rings, backing rings)
- Count number of timed fittings
• ESTABLISH JOINT VALUES IN AN ARRAY
• LOOP THROUGH THE ARRAY OF JOINTS
- Set SHOPJT = 9999 if joint on main pipe piece
- Set SHOPJT = 1 or 2 for all fitting joints
- Set SHOPJT = 0 if joint not a part of this detail or is screwed or threaded
ANY TIMED FITTING
NO
A
YES
• LOOP THROUGH THE ARRAY OF FITTINGS TO CHECK TYPE CODES
- Make sure every timed fitting has a type code. If a type code does not exist, create one from the fitting description.
- Check fittings with "miscellaneous" type codes to determine if they are welded like a boss. If so, set type code to "boss".
- Extract fitting size from description
• LOOP THROUGH THE ARRAY OF FITTINGS TO CHECK FOR SPECIAL FITTINGS
- Joints may be divided into two sides but only one side of the joint will be timed. Set joint to be timed to SHOPJT = 2 and other side of joint to SHOPJT = 1
TEMPLATE FROM SHIP
YES
ADD VALVE TO FTOTAL
NO

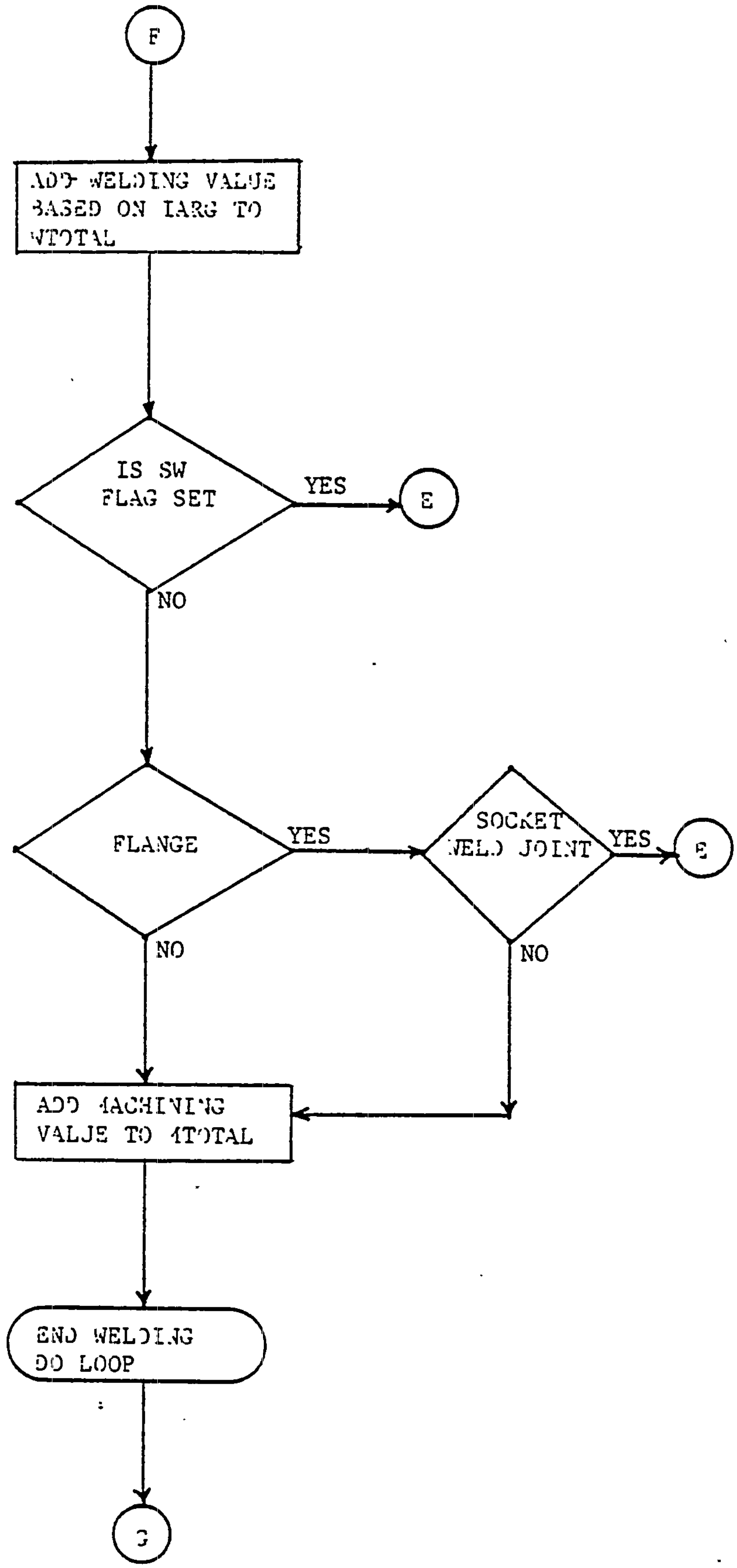

B
BEGIN FABRICATION DO LOOP 1, N
IS THIS A TIMED FITTING
NO
B
YES
USE SIZE OF FITTING TO CHOOSE ROW FROM FABRICATION MATRIX
FLANGE
YES
FLANGE TO FLANGE JOINT
NO
SLIP ON FLANGE
NO
C
YES
ADD VALUE TO FTOTAL
B
YES
ADD VALUE TO FTOTAL
D
NO
PIPE
YES
BRANCH
NO
C
YES
ADD VALUE TO FTOTAL
D
NO

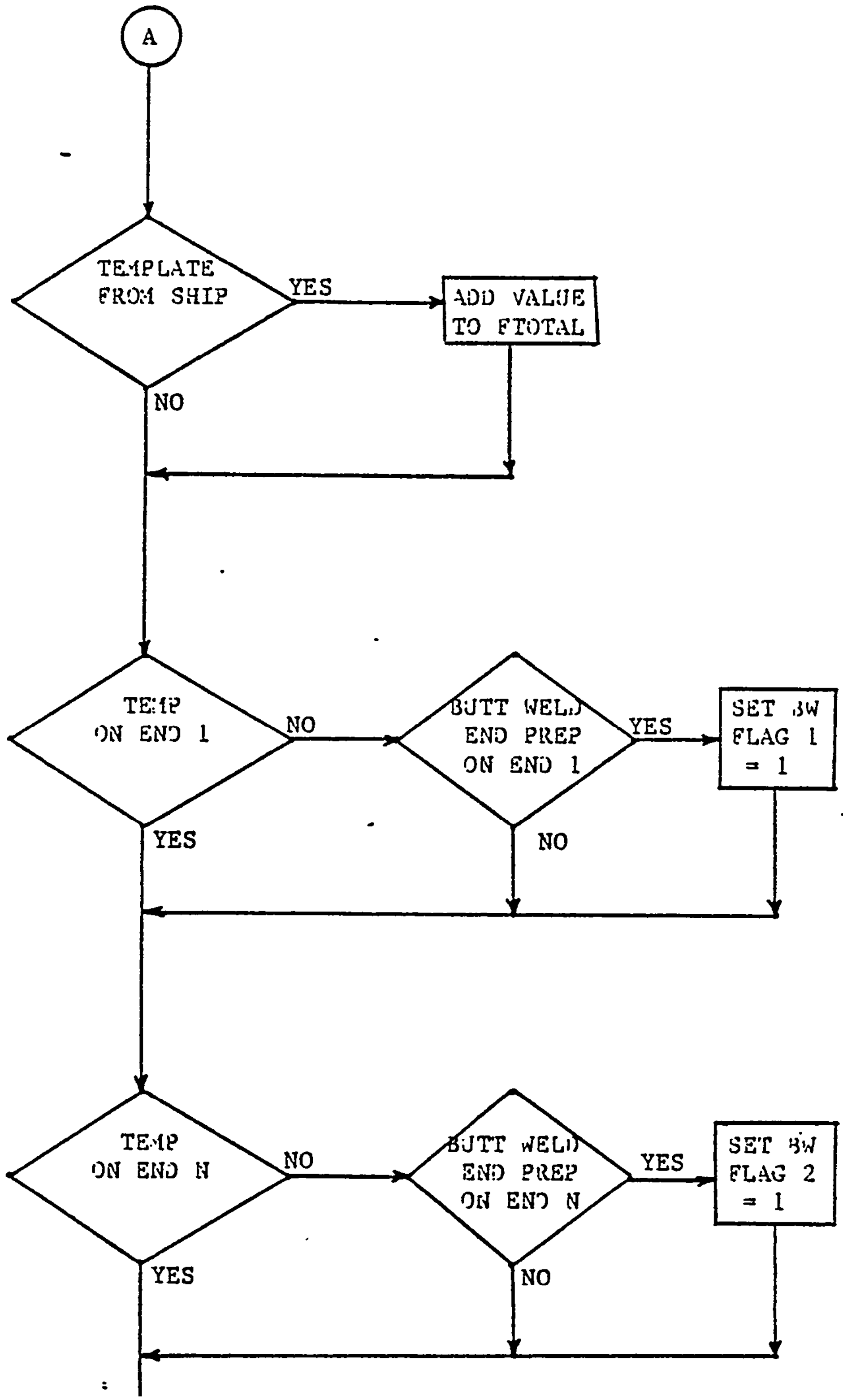

BOSS
YES
NO
ADD VALUE TO FTOTAL
WELD-O-LET
YES
NO
ADD VALUE TO FTOTAL
SLEEVE
YES
NO
ADD VALUE TO FTOTAL
C
MUST BE A STANDARD FITTING. ADD VALUE TO FTOTAL
BRAZED
YES
NO
ADD VALUE TO FTOTAL
ZERO JOINT FLAG (REMOVE 1 OR 2) SO JOINT WILL NOT BE CONSIDERED IN WELDING SECTION
END FABRICATION DO LOOP

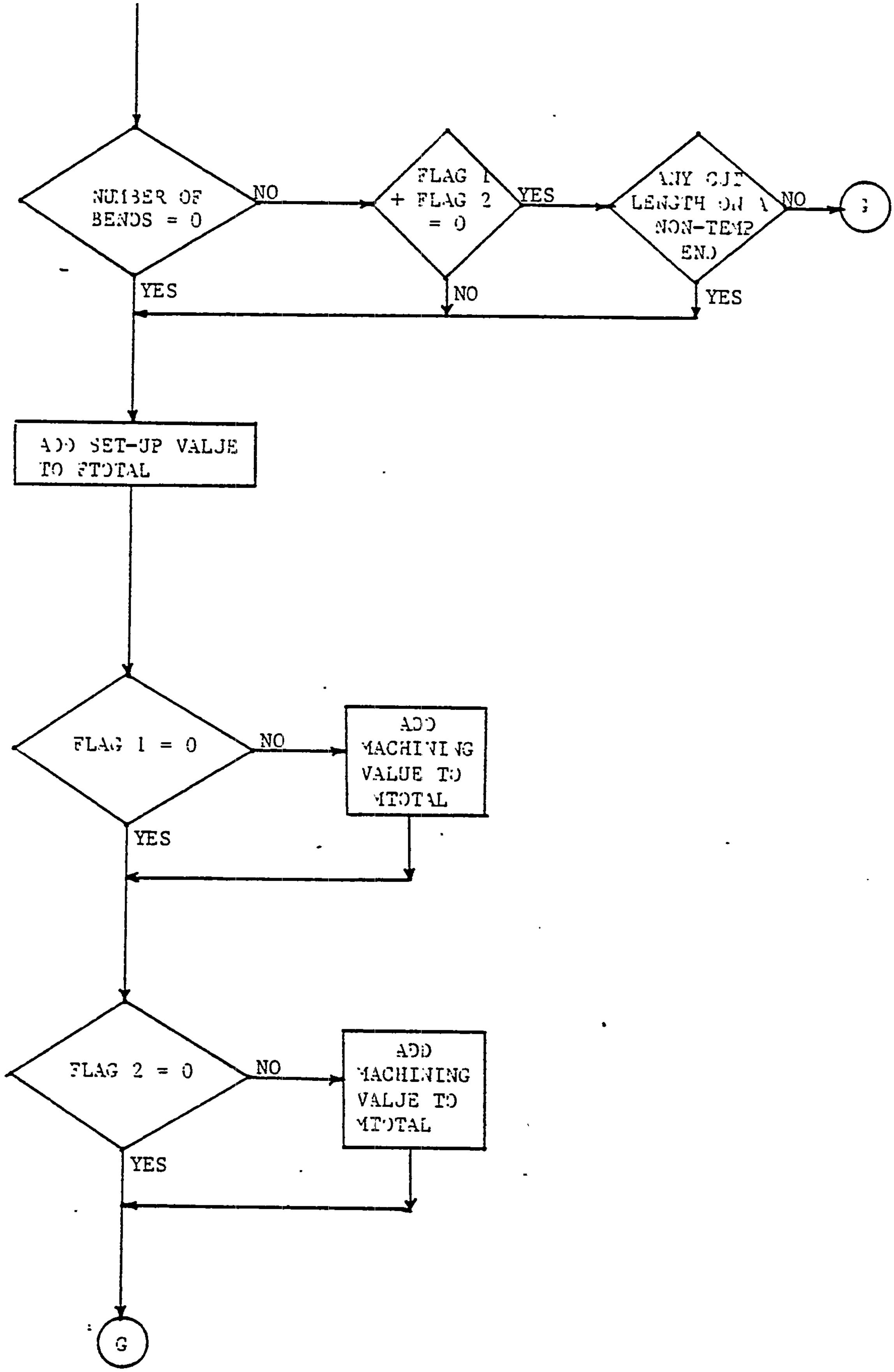

USE SIZE OF MAIN PIECE TO CHOOSE ROW FROM WELDING MATRIX
SET ALL FIRST FLAGS TO 0
E
BEGIN WELDING DO LOOP 1,N
IS THIS A TIMED FITTING
NO
YES
USE SIZE OF JOINT TO CHOOSE ROW FROM WELDING MATRIX
IS END PREP ON TIMED SIDE OF JOINT BLANK
YES
IS END PREP ON OTHER SIDE OF JOINT BLANK
YES
MUST NOT BE A TIMED JOINT
E
NO
NO
FLANGE
YES
FIRST FLANGE (FLAG=0)
YES
RESET FIRST FLANGE FLAG
SET IARG TO FIRST FLANGE VALUE
F
NO
NO
SET IARG TO FLANGE VALUE
F


BOSS OR WELD-O-LET
YES
ADD BOSS VALUE TO WTOTAL (WELDING)
ADD DRILL VALUE TO MTOTAL (MACHINING)
E
NO
SOCKET-WELD (SW) JOINT
YES
SET SW FLAG FOR MCHNG
CARBON STEEL
YES
FIRST CARBON STEEL SW
YES
NO
NO
SET IARG TO SW COLUMN VALUE
F
CHROME MOLY
YES
FIRST CHROME MOLY SW
YES
RESET FLAG FOR THIS MATERIAL
NO
NO
SET IARG TO SW COLUMN VALUE
F
SET IARG TO SW COLUMN VALUE
F
FIRST COPPER NICKEL SW
YES
NO
SET IARG TO SW COLUMN VALUE
F

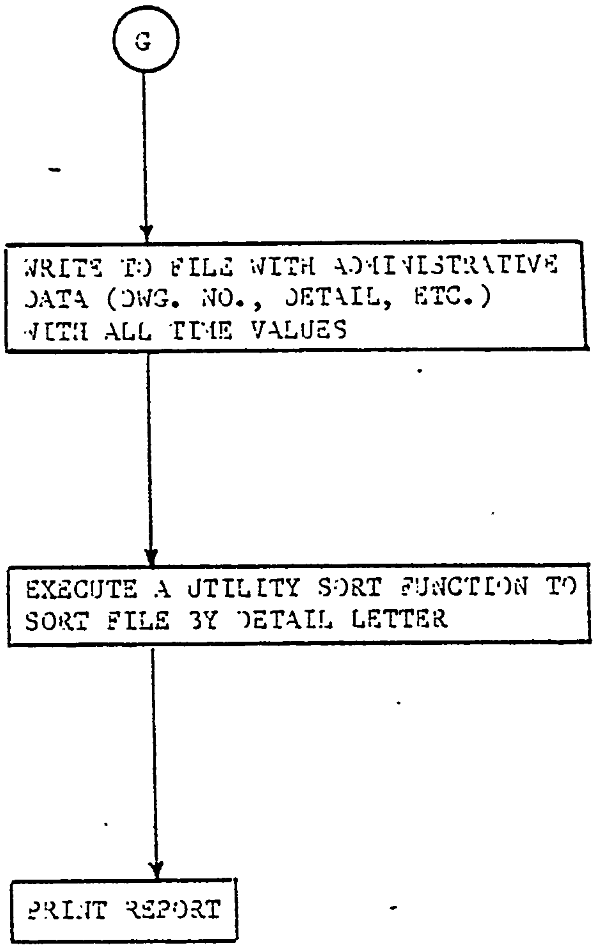

BUTT WELD (BW) JOINT
NO
YES
BLANK JOINT TYPE
NO
YES
E
PRINT JOINT TYPE ERROR MESSAGE
E
CARBON STEEL
YES
NO
FIRST CARBON STEEL BW
YES
NO
SET IARG TO BW COLUMN VALUE
F
CHROME MOLY
YES
NO
FIRST CHROME MOLY BW
YES
NO
SET IARG TO BW COLUMN VALUE
F
RESET FIRST BW FLAG FOR THIS MATERIAL
SET IARG TO BW COLUMN VALUE
F
FIRST COPPER NICKEL BW
YES
NO
SET IARG TO BW COLUMN VALUE


F
ADD WELDING VALUE BASED ON IARG TO WTOTAL
IS SW FLAG SET
YES
E
NO
FLANGE
YES
SOCKET WELD JOINT
YES
E
NO
NO
ADD MACHINING VALUE TO MTOTAL
END WELDING DO LOOP
G


A
TEMPLATE FROM SHIP
YES
ADD VALUE TO FTOTAL
NO
TEMP ON END 1
NO
BUTT WELD END PREP ON END 1
YES
SET BW FLAG 1 = 1
YES
NO
TEMP ON END N
NO
BUTT WELD END PREP ON END N
YES
SET BW FLAG 2 = 1
YES
NO



NUMBER OF BENDS = 0
NO
YES
FLAG 1 + FLAG 2 = 0
YES
NO
ANY CUT LENGTH ON A NON-TEMP END
NO
YES
G
ADD SET-UP VALUE TO FTOTAL
FLAG 1 = 0
NO
YES
ADD MACHINING VALUE TO MTOTAL
FLAG 2 = 0
NO
YES
ADD MACHINING VALUE TO MTOTAL
G


G
WRITE TO FILE WITH ADMINISTRATIVE DATA (DWG. NO., DETAIL, ETC.) WITH ALL TIME VALUES
EXECUTE A UTILITY SORT FUNCTION TO SORT FILE BY DETAIL LETTER
PRINT REPORT

APPENDIX B

Explanation of Flowcharts

APPENDIX B

Explanation of Flowchart

This detailed explanation of the program provides a step bv step analysis of the detailed flowchart presented in Appendix A.

The text is divided into six sections that correspond with the program flowchart:

- Bending Values Development
- Fabrication Values Development
- Welding Values Development
- Machining Values Development
- Pipe Details Without Fittings
- Print Out

Excerpts from the program flowchart are included with each section.

<u>**Bending Values Development**</u>

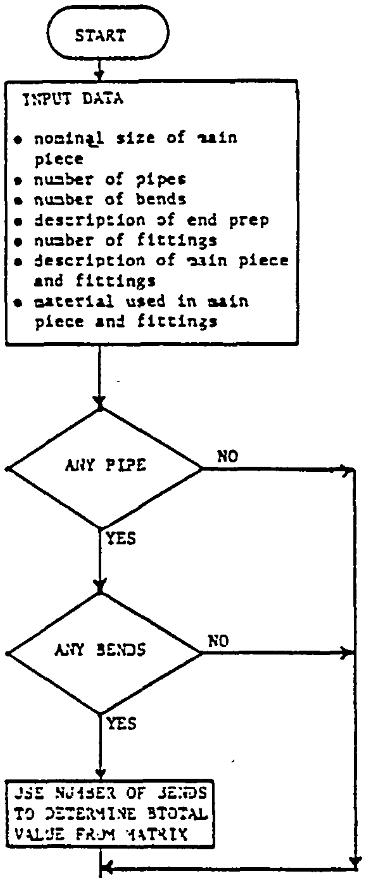


Fig. 1

Bending

Nominal Pipe Size	Number of Bends 1	2	3	4	5
Applies To All Bending Machines					
1/2" Thru 3 1/2"	1	1	1	1	1
4" Thru 6"	1	1	1	1	1
8" Thru 12" +	1	1	1	1	1

Fig. 2

Data from the pipe detail manufacturing system is used to determine the number of bends and the main pipe piece size. The standard times for bending are established in a matrix (Fig. 2) which is identical to the matrix on the planner's pick sheet. The outside diameter of the main pipe piece determines which row is applicable and the number of bends required determines the applicable column. The program accesses the standard time and records the total bending value for the detail.

Fabrication Values Development

Fitting information is collected and organized before the fabrication, welding, and machining values are calculated. Fitting data, including the description, material type, and end preparation, is taken from the computer-aided piping design system where it has already been used to develop the pipe detail manufacturing record. If the pipe detail is bent but has no fittings the program advances to the point immediately following the determination of the welding values (A). If the pipe detail has fittings, the fabrication and welding values are determined.

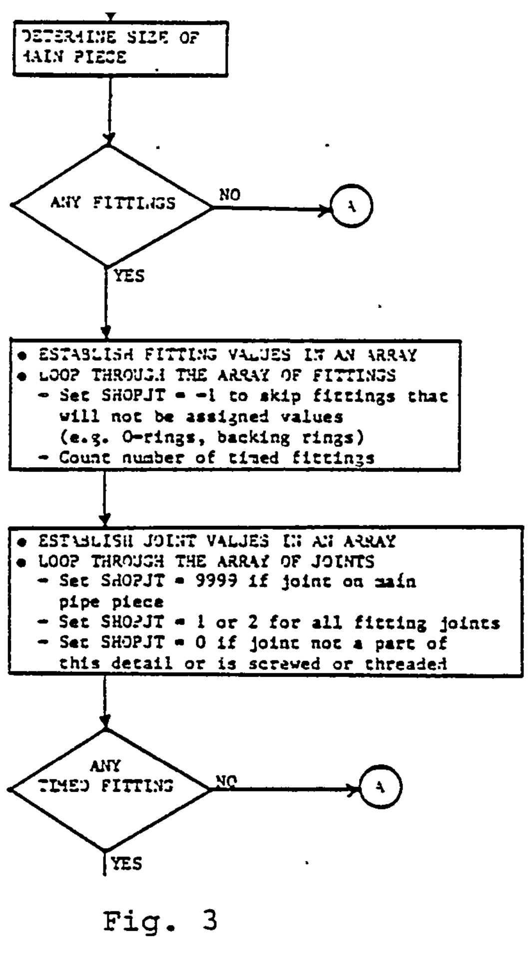


Fig. 3

The input data is reviewed and the fittings are established in an array. Fittings that are designated as having no value (e.g. O-rings, backing rings, etc.) are flagged so they will be excluded from consideration in the remainder of the program. These excluded fittings will be specific to each shipyard depending on the application of their work packages. The number of remaining fittings is then determined by subtracting the number of excluded fittings from the total number of fittings.

After the fitting array is set up, another array containing the information pertaining to the joints (including end preparation) is established. A direct correspondence exists between these arrays. The array of joint sizes allows the program to correctly handle a number of special situations. These situations may exist for reducing fittings, which can be . different sizes on each end, and for bosses, branches, or weld-o-lets which may differ in size from the piece to which they are attached. Joints that are screwed or threaded are designated as having no value and are flagged so they will be excluded from consideration in the program. A loop is made through the array to identify excluded joints, joints on the main pipe piece, and fitting joints.

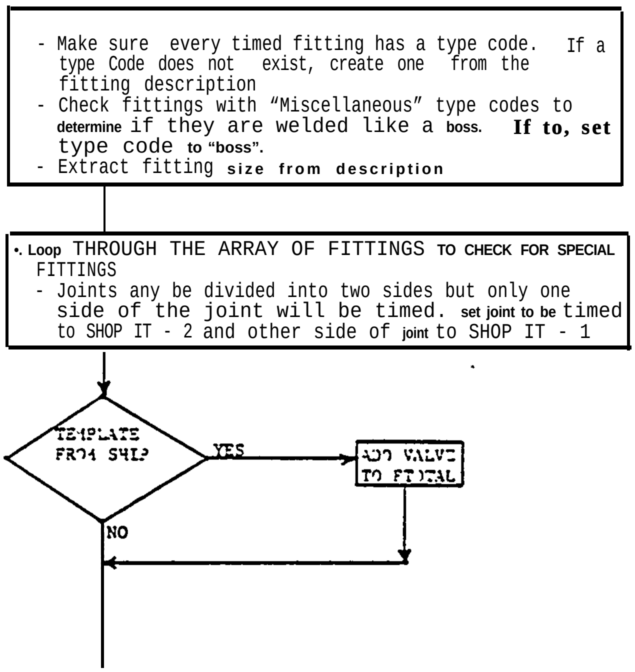


Fig. 4

The next step is to loop through the fitting array to check for type codes. Using the descriptions of the fittings in the array the type codes are ,extracted from the catalog of pipe detail parts. If the fitting type code is not in the catalog, the fitting description is scanned and the type code created.

Another loop is made through the array of fittings to determine how the standards for joints at special fittings will be applied. Each joint is divided into two sides, based on fitting descriptions and size information generated by computer-aided piping design system. Each side of the joint is analyzed to determine which side will be used to determine the standard.

In a separate routine, the notes from the pipe detail manufacturing record are scanned to determine if the detail has a "Template From Ship" note. This note requires that a template be taken from the ship in order to construct the pipe detail. This operation requires that an additional value based on the outside diameter of the main pipe piece be added to the fabrication total.

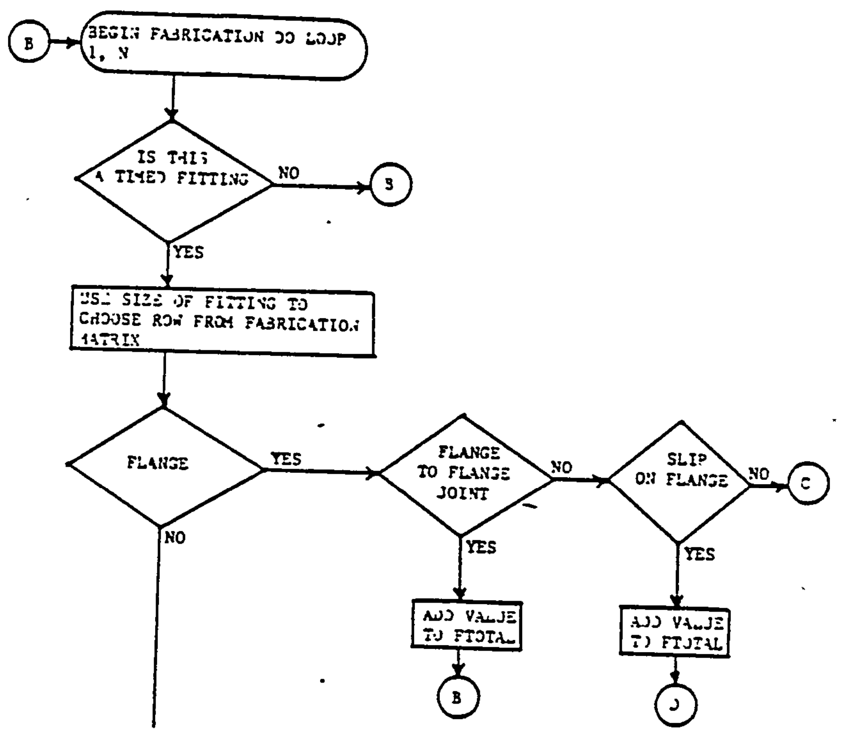


Fig. 5

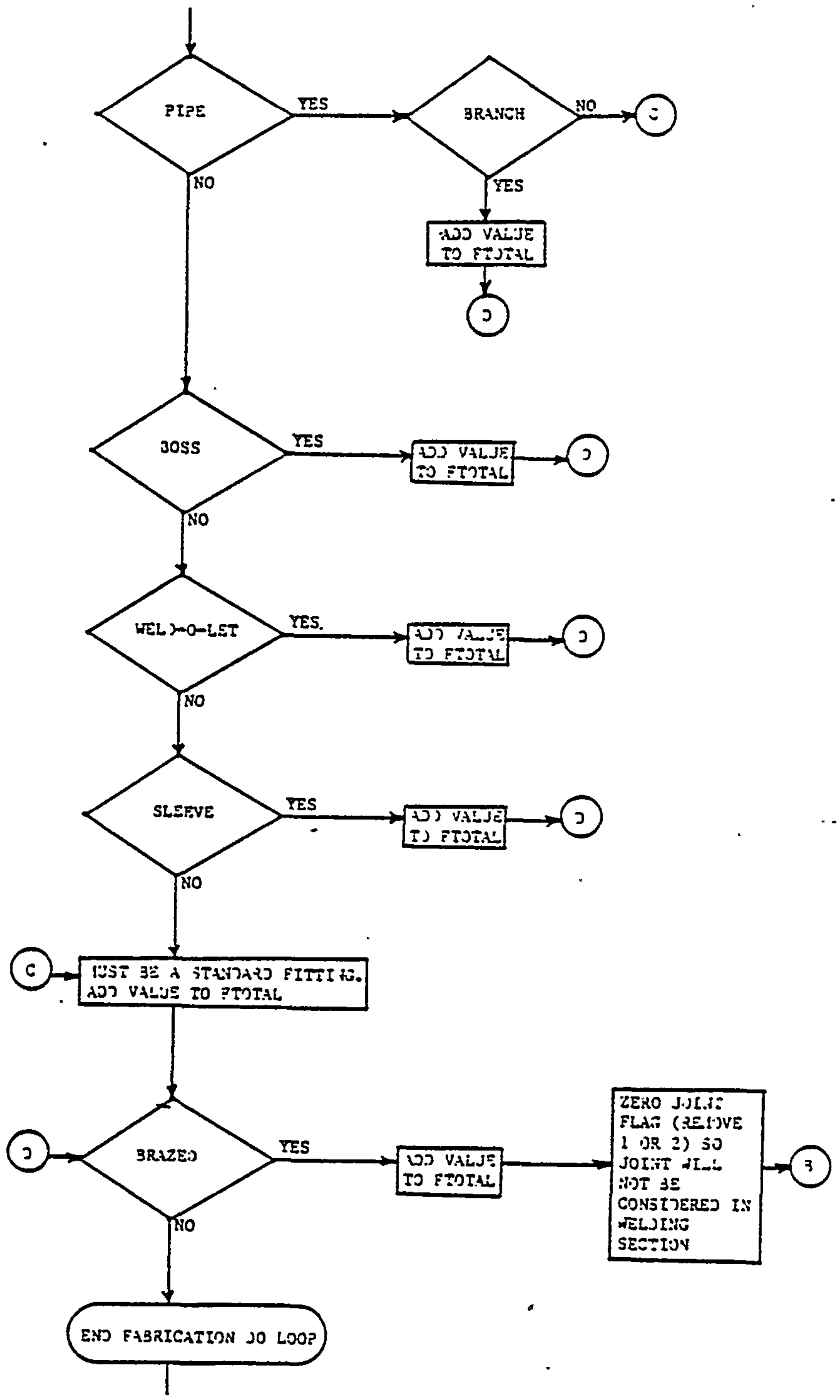

PIPE
YES
BRANCH
NO
YES
NO
BOSS
YES
NO
YES.
NO
SLEEVE
YES
NO
BRAZED
YES
NO

Fig 6

The fitting outside diameter, description, end preparation, and type code are used to determine the fabrication values from the matrix (Fig. 7). The outside diameter of the fitting determines which row of the matrix is applicable for an operation. Each column is checked until the correct fitting. type is found. All the fittings for the detail are looped through and the standard time for each fabrication activity is added to the overall detail fabrication total.

FABRICATION

A	B	C	D	E				F		G	H
Pipe or Fitting Diam.	Set-Up The Job	Fittings	Slip on Flange	Special Fittings				Brazing		Template Set-Up	Assemble Flange : Flange
				Branch	Boss	Weld-o-let	Sleeve	Fitting	Flange		
1/2" Thru 3"	1	1	1	1	1	1	1	1	1	1	1
3 1/2" Thru 5"	1	1	1	1	1	1	1	1	1	1	1
5 1/2" Thru 8"	1	1	1	1	1	1	1	1	1	1	1
8 1/2" Thru 12"	1	1	1	1	1	1	1	1	1	1	1
12 1/2" Thru 16"	1	1	1	1	1	1	1	1	1	1	1
16 1/2" Thru 20"	1	1	1	1	1	1	1	1	1	1	1
20 1/2" Thru 24 1/2"	1	1	1	1	1	1	1	1	1	1	1

Fig. 7

The pipe shop specifications require that any brazing be included in the fabrication step. The end preparation required for each fitting is checked to determine if brazing is required. If the fitting is brazed, the joint flag is removed so the joint will not be considered in the welding section of the program. The brazing standard times are added to the fabrication total for each detail.

Welding Values Development

The welding values are determined joint by joint, they are not looped through an array like the fabrication values. The outside diameter of the piece at the joint determines which row of the matrix (Fig. 11) is applicable for an operation. Before the welding values are determined, flags are set to keep track of the first weld of each weld type. This is necessary because the first joint requires preparation and set-up time.

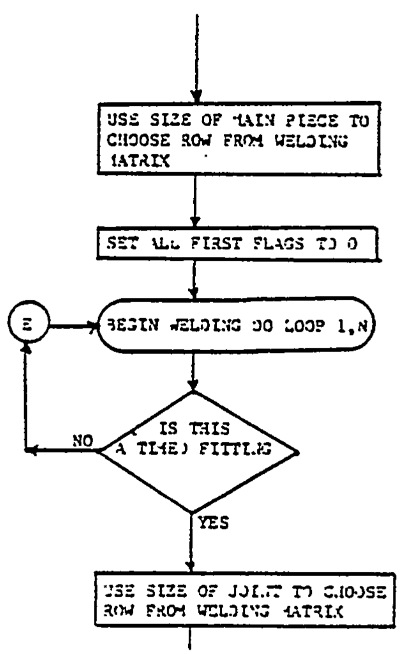


Fig. 8

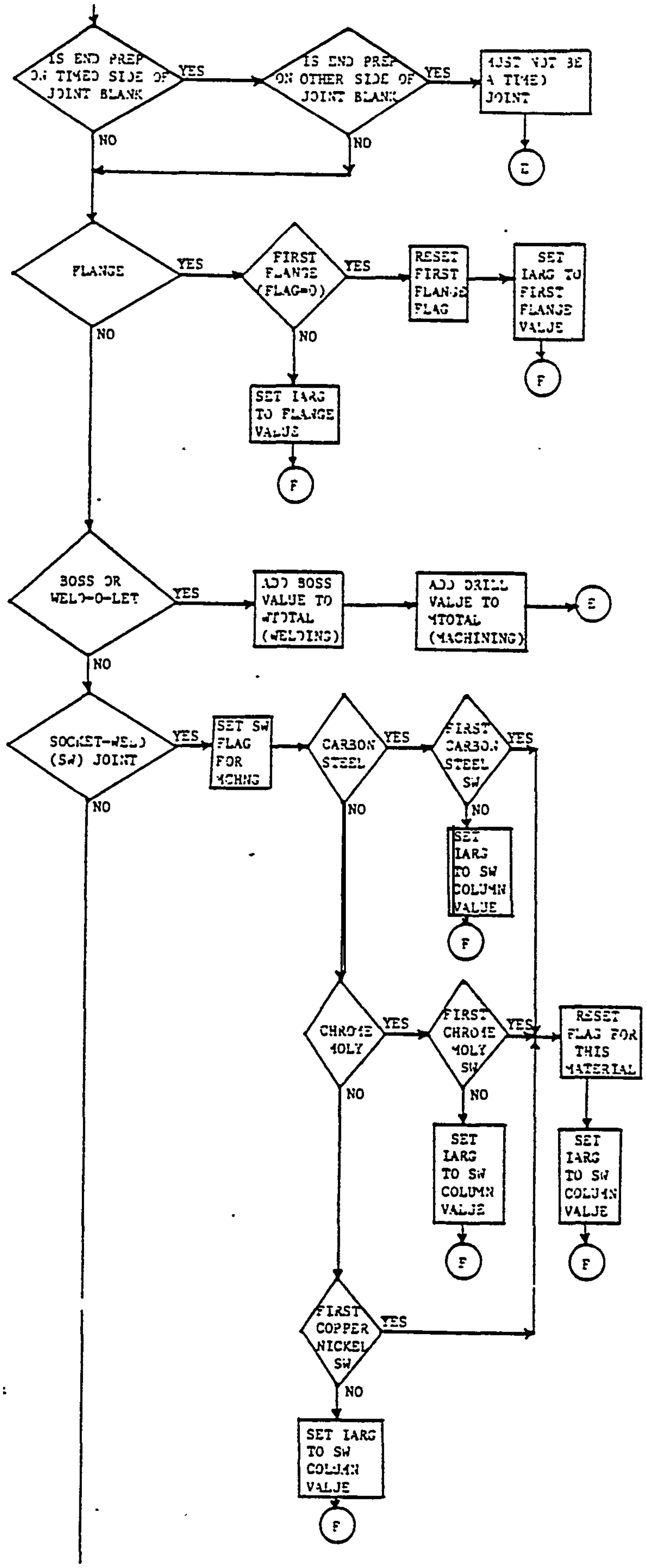
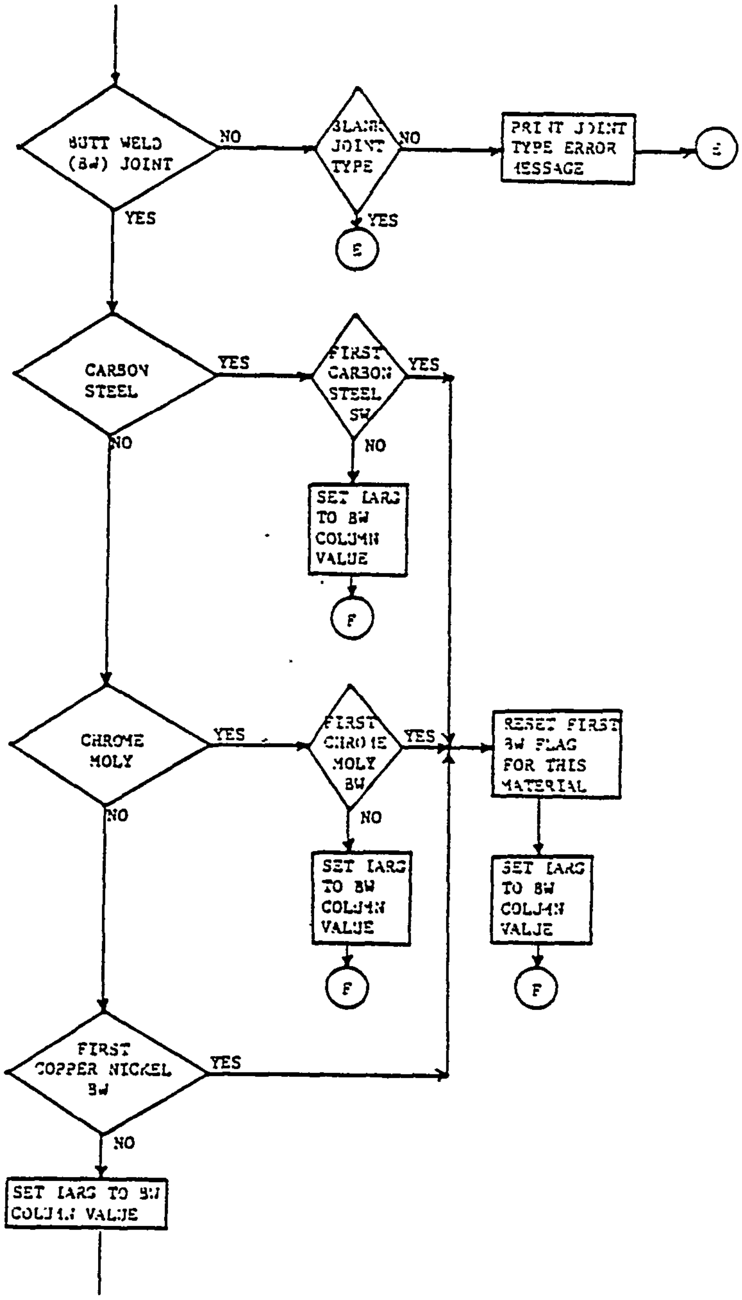

IS END PREP ON TIMED SIDE OF JOINT BLANK
YES
NO
IS END PREP ON OTHER SIDE OF JOINT BLANK
YES
NO
MUST NOT BE A TIMED JOINT
E
FLANGE
YES
NO
FIRST FLANGE (FLAG=0)
YES
NO
RESET FIRST FLANGE FLAG
SET IARG TO FIRST FLANGE VALUE
F
SET IARG TO FLANGE VALUE
F
BOSS OR WELD-O-LET
YES
NO
ADD BOSS VALUE TO WTOTAL (WELDING)
ADD DRILL VALUE TO MTOTAL (MACHINING)
E
SOCKET-WELD (SW) JOINT
YES
NO
SET SW FLAG FOR MCHNG
CARBON STEEL
YES
NO
FIRST CARBON STEEL SW
YES
NO
SET IARG TO SW COLUMN VALUE
F
CHROME MOLY
YES
NO
FIRST CHROME MOLY SW
YES
NO
RESET FLAG FOR THIS MATERIAL
SET IARG TO SW COLUMN VALUE
F
SET IARG TO SW COLUMN VALUE
F
FIRST COPPER NICKEL SW
YES
NO
SET IARG TO SW COLUMN VALUE
F

Fig. 9



BUTT WELD (BW) JOINT
NO
YES
BLANK JOINT TYPE
NO
YES
PRINT JOINT TYPE ERROR MESSAGE
E
E
CARBON STEEL
YES
NO
FIRST CARBON STEEL BW
YES
NO
SET IARG TO BW COLUMN VALUE
F
CHROME MOLY
YES
NO
FIRST CHROME MOLY BW
YES
NO
SET IARG TO BW COLUMN VALUE
F
RESET FIRST BW FLAG FOR THIS MATERIAL
SET IARG TO BW COLUMN VALUE
F
FIRST COPPER NICKEL BW
YES
NO
SET IARG TO BW COLUMN VALUE

Fig. 3.0

The end preparation requirements are checked to make sure that the fitting requires welding and to determine the joint type. The type of fitting is checked to determine the column section of the matrix (Fig. 11). If the fitting is a boss or flange the standard time from the matrix is selected according to size, regardless of the joint type. Other fittings are selected according to the joint type and material type. The standard time for each joint is determined and the welding value for the detail is incremented joint by joint.

WELDING

Joint Dia. or Nom. Pipe Size	Socket Weld						Flange		Butt Weld						Boss
	Carbon Steel		CUNI, Cres		Chrome-Moly				Carbon Steel		CUNI, Cres		Chrome-Moly		
	First Joint	Each Add-on	First Joint	Each Add-on	First Joint	Each Add-on	First Flange	Each Add-on	First Joint	Each Add-on	First Joint	Each Add-on	First Joint	Each Add-on	Each Joint
1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3/4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1 1/4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4 1/2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Fig. 11

Machining Values Development

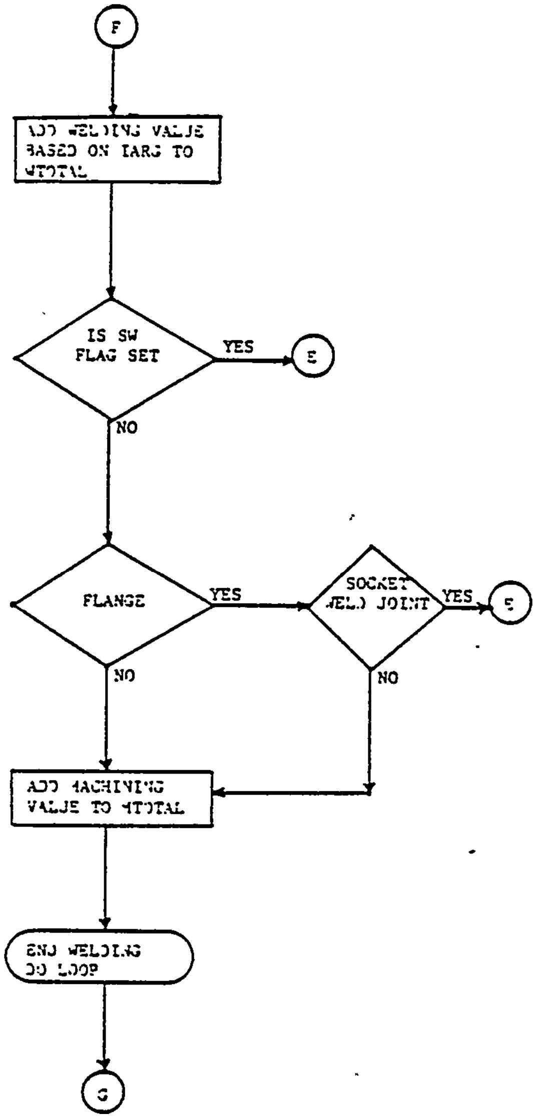


Fig. 12

MACHINING
PER PIPE END
1 Man Operation

Non. Pipe Size	**Straight** Level Operation	Combination J Level 6 Counter Bore
10" - 14"		

Fig. 13

The machining values are based on the type of welding involved and the end preparation required for a piece. Since machining is directly related to welding it is included within the welding section of the program but is considered a separate operation for standards application.

The machining required for each joint is based on the fitting type and the welding involved. If the fitting is a flange, it must be determined whether a butt weld or a socket weld is required. If a socket weld is required for a flange end prep, no machining value is applied. If a butt weld is required for a flange end prep; the machining value is applied. If the fitting is a boss, the drilling value is added to the machining value directly after the welding value for bosses is added to the welding total.

The machining values for the other joints are based on the type of welding required. If a socket weld is required, no machining values are applied. If a butt weld is required, the machining value is for the time spent to bevel the end of the pipe prior to welding. Therefore, a machining value is not applied if the joint is a fitting to fitting joint.

The outside diameter of the piece determines which row of the matrix (Fig. 13) is applicable for an operation. The column is determined by the type of machining operation required for particular weld types. According to Newport News Shipbuilding specifications, the Combination J Bevel & Counter Bore is used only on one particular weld type, all other operations use Straight Bevels. The machining values for each operation are determined and added to the maching total.

Pipe Details Without Fittings

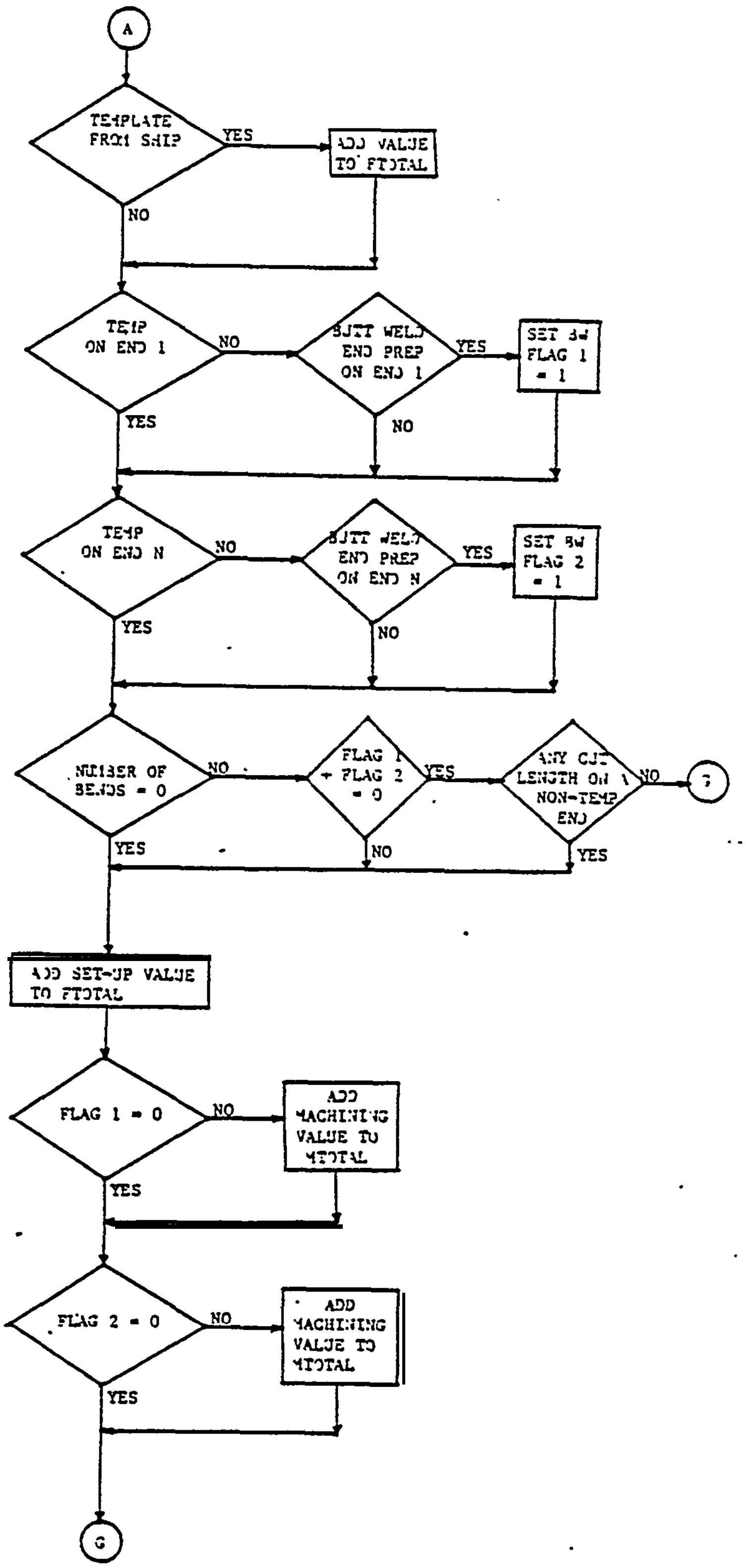


Fig. 14

Before the value totals are printed, the pipe details without fittings are checked for fabrication requirements. If a "Template From Ship" is required, the value for additional set-up time is designated as part of the fabrication value.

Next, the end preparation requirements are checked to determine if a templated end is left on either end of the main pipe piece. This templated end consists of additional length at the end of the piece of pipe that can be cut to fit the work already installed on the ship. If there is a templated end, then that end of the pipe is not prepared and a machining value is not applied. If there is not a templated end, then either one or both ends of the piece may require butt weld end preparation. If the end preparation is required, flags are set so that machining values will be applied.

If the pipe is bent the end preparations are checked. If butt weld end preps were not required and a specified cut length on a non templated end was not specified then the program advances to print out the standard values. If butt weld end preps were required then the set-up value is added to the fabrication total and the machining total. If the pipe is not bent, the set-up value is added to the fabrication total and any required machining values are added to the machining total.

Print Out

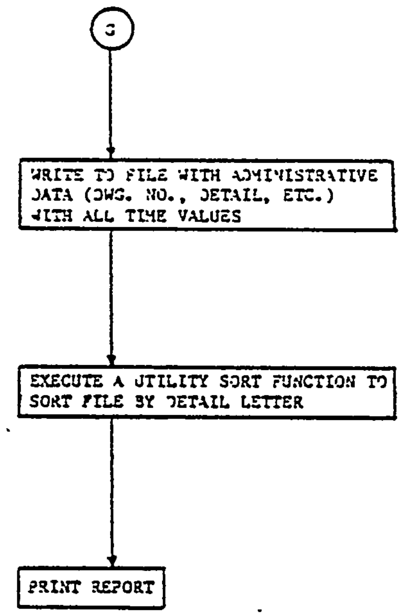


Fig. 15

After the bending, fabrication, welding and machining values are determined, the total value for each operation on a detail is written to a file. This record also includes administrative data, drawing numbers, and the pipe detail identifier. A utility sort function is performed to sort the file by detail identifier. A print out of the details, with the standard time values, is provided to the planner when developing, the work packages.

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INCREASING PRODUCTIVITY THROUGH METHODS IMPROVEMENT

By

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ABSTRACT

The SNAME Ship Production Committee's SP-8 Panel on Industrial Engineering's primary objective has been to increase productivity in the Shipbuilding Industry. Since the Panel's conception, it has introduced a number of Industrial Engineering techniques to improve the utilization of our two most important resources, men and machines. One can not function without the other, and only through proper management will optimum productivity be achieved.

One of the elements of good management is to encourage and pursue Methods Improvement at all levels of the organization. Due to the size of our product, we are led to believe that in order to improve, a major Methods change must occur. To some extent, this is true--such as the introduction of Group Technology, which has an effect on our entire organization. Changes like this must occur; however, we must not forget the importance of productivity improvement of each individual task, which, when combined has a tremendous impact on the total productivity picture.

The use of Industrial Engineering Techniques provides for a good, solid evaluation of tasks to boost productivity. The SP-8 Panel has sponsored a number of Methods Engineering Workshops to acquaint shipyard personnel with the techniques that are available, and how to use them. Workshop attendees have been introduced to work sampling, operations and flow process charting, operations analysis, and relationship charting. With these, an individual can systematically perform an analysis on any size task, and produce facts about the operation from which decisions can be made to improve productivity.

Substantial productivity gains can be made through the application of Industrial Engineering Techniques.

INTRODUCTION

In order to stay in business in today's 'economy we have to build and repair ships tomorrow with better productivity than we did yesterday. Substantial productivity gains can be made through the application of basic industrial engineering techniques; one of these being methods improvement.

Increasing productivity thru methods improvement is currently used extensively in many industries throughout the world, but little in U.S. Shipyards. There is a need to improve and become more competitive. Being more competitive by improving manufacturing techniques will result in more jobs, better wages, increased benefits, job security and many other advantages.

This paper discusses productivity and how to improve it, the productivity improvement attitude and the techniques used. The primary emphasis is on utilizing industrial engineering techniques to implement methods improvement.

In 1981 the SNAME Panel SP-8 on Industrial Engineering commissioned the Institute of Industrial Engineers to develop and put on a 5-day workshop to train shipyard personnel in the techniques of methods improvement with the ultimate goal of improving manufacturing productivity in the yards. The workshop material is the end result of several hundred hours of research and development by specialists in training and shipyard industrial engineers. Properly used, they can be the core (or improve your present program) of a valuable and effective program for Industrial Engineers, IE technicians, Production Engineers, Foremen, Supervisors, and Operations Managers.

Methods Improvement Awareness

What Is Productivity

Productivity may be defined as follows:

"Productivity is the ratio of output to total inputs"

Put in simpler terms, productivity, in the sense in which the word is used here, is nothing 'more than the arithmetical ratio between the amount produced and the amount of resources used in. the course of production:

- ° Land
- ° Materials
- ° Machinery
- ° Manpower
- ° Utilities

The productivity of labor, land, materials, or machines may have increased, but this bare fact does not in itself tell anything about the reasons why it has increased. An increase in the productivity of labor, for example, may be due to better planning of the work on the part of the management or to the installation of new machinery. An increase in the productivity of materials may be due to greater skill on the part of workers, to improved designs, and so on.

0 Productivity of Land

The productivity of land used for shipbuilding or repair may be said to have been increased if additional output can be met without increasing the acreage to support it. One such way to increase the productivity of land would be to

utilize storage racks rather than spread the material out on the ground. Therefore, the productivity of that land, in the storage sense, has been increased.

- Productivity of Materials

  If a skillful burner is able to cut eleven fitting saddles from a plate from which an unskillful burner can only cut ten, in the hands of the skillful burner the plate was used with 10 percent greater productivity.

- Productivity of Machines

  If in a machine shop a machine tool has been producing forty pieces per day and through the use of improved cutting tools its output in the same time is increased to fifty pieces, the productivity of that machine has been increased by 25 percent.

- Productivity of Men

  If a grit blaster has been cleaning thirty square-feet of steel per hour and an improved method of blasting has been implemented which will enable him to cover forty square-feet an hour, the productivity of that man has increased by 33-1/3 per cent.

In each of these examples output-or production-has also increased, and each case by exactly the same percentage as the productivity. But an increase in production does not by itself indicate an increase in productivity. If the input of resources goes up in direct proportion to the increase in output, the productivity will stay the same. And if input increases by a greater percentage than output, higher production will be being achieved at the expense of a reduction in productivity.

In short, higher productivity means that more is produced with the same expenditure of resources, i.e., at the same cost in terms of land, materials, machine-time, or labor; or alternatively that the same amount is produced at less cost in terms of land, materials, machine-time, or labor used up, thus releasing some of these resources for the production of other things.

Productivity Improvement Climate

Many people have been misled into thinking of productivity exclusively as the productivity of labor, mainly because labor productivity usually forms the basis for published statistics on the subject. Productivity should be treated as one making the best possible use of all the available resources, and attention will constantly be drawn to cases where the productivity of materials or plant is increased.

The main responsibility of raising productivity rests with management. Only management can introduce and create a favorable climate for a productivity program and obtain the cooperation and involvement of the workers which is essential for real success.

Even with good planning, steps taken to raise productivity will probably meet with resistance. This resistance can generally be reduced to a minimum if everybody concerned understands the nature of a reason for each step taken and has some say in its implementation.

Productivity Improvement Attitude

Methods improvement is largely a matter of systematic application of sound, practical common sense. One may say that it is common sense systematically applied. There are a large number of highly specialized methods improvement techniques available today. These techniques should be utilized to' identify potential improvements along with common sense to determine if the proposed method improvement is practical.

The most important single asset to success with methods improvement is mental attitude. A desire to ask questions and to be "down right curious" often leads to sizable methods improvements. A healthy curiosity is sometimes far more valuable in connection with methods study than a thorough knowledge of the job. When a person has achieved a good working knowledge of the job, there may be a tendency to feel that the best methods have been attained and that additional methods improvement work is not necessary. This is not true. If the attitude that "no improvement can be made" is prevalent, nobody will try to make any improvement. Thus, the possiblity of a better method may die on the spot.

A slogan used by many industrial engineers is: "With sufficient study, any method can be improved." Of course, practical limitations prevent a method from being improved to the point of perfection. From a theoretical standpoint, however, methods improvement can never be complete as long as the operation itself exists. It is better to call a methods improvement "the best method yet devised."

Techniques

Methods Engineering Discipline

Methods Engineering embraces several techniques, but in particular, method study and work measurement.

Method study is the systematic recording and critical examination of existing and proposed ways of doing work, a means of developing and applying easier and more effective ways of doing things, and reducing costs.

Work measurement is the application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance.

Method study and work measurement are, therefore, closely linked. Methods study is concerned with the reduction of work content of a job or operation, while work measurement is mostly concerned with the investigation, identification and reduction of ineffective time.

Work measurement, as the name suggests, provides management with a means of measuring the time taken in the performance OR an operation or series of operations in such a way that ineffective time is identified and can be separated from effective time. In this way it's existance, nature and extent become known where previously they were concealed within the total. Once the existance of ineffective time has been revealed and the reasons for it tracked down, steps can usually be taken to reduce it.

Work measurement has another role to play. Not only can it reveal the existance of ineffective time; it can also be used to set standard time for carrying out the work, so that, if any ineffective time does creep in later, it will immediately be shown up as an excess over the standard time and will thus be brought to the attention of management.

Work measurement is more likely to show up the management itself than the poor behavior of workers. Because of this, it is apt to meet with 'far greater resistance than method study. Nevertheless, if efficient operation of a yard as a whole is being sought, the application of work measurement, properly carried out, is one of the best means of achieving it.

The objectives of method study are:

- The improvement- of processes and procedures,
- The improvement of yard, shop, and workplace layout and of the design of plant and equipment,
- Economy in human effort and the reduction of unnecessary fatigue and avoidable delays,
- Improvement in the use of materials, machines and manpower,
- The development of a better physical working environment,
- The assurance that an operation is properly staffed.

There are a number of method study techniques suitable for tackling problems on all scales from the layout of a complete shipyard to the smallest movement of workers on a repetitive job. In every case, however, the method of procedure is basically the same and must be carefully followed. There are no short cuts.

Basic Procedure

When a problem is examined there should be a definite and orderly sequence of analysis. The basic procedure for conducting any methods study is as follows:

- SELECT the work to be studied, define the problem,
- RECORD all the 'relevant facts about the present method by direct observation, involve those who will be affected,
- EXAMINE those facts critically and in ordered sequence, using the techniques best suited to the purpose,
- DEVELOP the most practical, economic and effective solution or improved method having due regard to all factors,
- DEFINE the new method so that it can always be identified,
- SELL the change to assure a smooth transition to the new method,
- INSTALL that method as standard practice,
- MAINTAIN that standard practice by regular routine checks or through the use of a Labor Reporting System.

These are the eight essential stages in the application of method study: none can be excluded. Strict adherence to their sequence, as well as to their content, is-essential for the success of the project.

Do not be deceived by the simplicity of the basic procedure into thinking that method study is easy and therefore unimportant. On the contrary, method study may on occasion be very complex and difficult.

Selecting Work to be Studied

When considering whether a method study investigation of a particular job should be carried out, certain factors should be kept in mind. These are:

- Economic considerations
- Technical considerations
- Human or psychological factors

1. Economic Considerations will be important at all stages. It is obviously a waste of time to start or to continue a long investigation if the economic importance of the job is small, or if it is one which is not expected to run for long. The first questions must always be: "Will it pay to begin a method study of this job?", and: "Will it pay to continue this study?"

   Obvious early choises are:

   - "Bottlenecks" which are holding up production operations,
   - Movement of material over long distances between shops, or operations involving a great deal of manpower or where there is repeated handling of material,
   - Operations involving repetitive work using a great deal of labor and liable to run for a long time.

2. <u>Technical Considerations</u> will normally be obvious. The most important point is to make sure that adequate technical knowledge is available with which to carry out the study, and that the proposed solution will work. Examples are:

(a) The use of pre-construction primer versus raw steel in the construction process might bring increased productivity of facilities and labor, but there may be technical reasons why a change should not be made. This calls for advice of specialists in welding, burning, coatings, etc.

(b) A machine tool constituting a bottleneck in production is known to be running at a speed below that at which the high-speed cutting tools will operate effectively. Can it be speeded up, or is the machine itself not robust enough to take the faster cut? This is a problem for the machine-tool expert.

3. <u>Human or Psychological Factors</u> are among the most important factors to be taken into consideration, since mental and emotional reactions to investigation and changes of method have to be anticipated. If it appears that the study of a particular job appears to be leading to a great deal of unrest or ill feeling, leave it alone for the time being, however promising it may be from the economic point of view. If other jobs are tackled successfully and can be seen by all to benefit the people working on them, opinions will change and it will be possible, in time, to go back to the original choice.

Involving the people affected almost always helps the improvement process.

It is important to set clearly-defined limits to the scope of the investigation. Method study investigations often reveal scope for even greater savings and there is a strong temptation to go beyond the immediate objective. The original objectives should be adhered to; and any jobs shown up as offering scope for big improvements through method study should be noted and tackled separately.

Record and Analyze the Method

After selecting the work to be studied, record all the facts relating to the existing method. The success of the whole procedure depends on the accuracy with which the facts are recorded, because they will provide the basis of both the critical examination and the development of the improved method. It is therefore essential that the record be clear and concise.

The usual way of recording facts is to write them down. Unfortunately, this method is not suited to the recording of the complicated processes which are so common in shipbuilding. This is particularly so when an exact record is required of every minute detail of a process or operation. To describe everything exactly that is done in even a very simple job would probably result in several pages of closely written script, which would require careful study before anyone reading it could be quite sure that he had grasped all the details.

To overcome this difficulty other techniques or "tools" of recording have been developed, so that detailed information may be recorded precisely and at the same time in standard form, in order that it may be readily understood by all.

The most commonly used of these recording techniques are charts and diagrams. There are several different types of standard charts available, each with its own special purpose.

Operation Analysis

Operation Analysis is a systematic procedure used to study all the factors which could affect the method of performing an operation economically. Through this analysis, the present best available method of performing each necessary step of an operation is determined and improved if possible.

The Operations Analysis Form was designed to act as a guide to systematically analyze operations. The first page of the six page form is shown as Fig. 1. It directs the analysis through the key factors and ensures that none are over looked. The primary factors which should be reviewed in every operation are:

1. Purpose of operation
2. Part design
3. Material
4. Material handling
5. Inspection requirements
6. Process analysis
7. Design of work

SH1PYARD OPERATION ANALYSIS FORM

Page 1 of 6

OPERATION ______ DATE ______

PART NAME ______ PART NO. ______ DWC. NO. ______

ANALYZED BY ______ HULL NO. ______

ACTION	ANALYSIS CONSIDERATIONS	DESCRIPTION
	Is the operation necessary?	1. PURPOSE OF OPERATION
	Can operation be eliminated by improving previous operat1ons?	
	Can one or more operations be combined?	
	Can operations be changed to simplify succeeding operations?	
	Are the intended results accomplished?	
	Does your competitor have a better wny?	
	Can the part be purchased at a lower cost?	
	Are inefficient operations tolerated just because they run smoothly and predictably?	
	If the operation has been added to correct a following difficulty, is it possible that the corrective operation is more costly than the difficulty itself?	
	Are all parts necessary?	2. PART DESIGN (Indicate possible improvements)
	Can standard parts be used or converted to do the job?	
	Can one part be redesigned to function for two?	
	Does design permit the most economical means of Manufacturing?	
	Is "excess" material minimized?	
	Do you have good relations with engineering and the sold loft to effect improvements and correct mistake?	
	Can scrap be reduced?	3. MATERIAL A. PRESENT MATERIAL
	Can part be made from scrap?	
	Can parts be nested to reduce scrap?	
	Would material change reduce manufacturing costs?	
	Can lcss expensive material be used?	
	Is material always availablc before job is scheduled to start?	

Fig. 1 OPERATIONS ANALYSIS FORM

8. Workplace layout, machine, and tools
9. Working conditions
10. Methods comparison chart

Process Charts

"A process chart is a schematic or tabular representation of the sequence of all relevant actions or events - operations, transportation, inspection, delays, storages - occuring during a process or procedure." The intent of the process chart is to provide a graphic representation of a process so that present and proposed methods could visually be compared in chart form.

The flow process chart tracks five activities: operations, transportation, inspection, delays and storage. This chart can be used to analyze the sequence of operations as a part goes through and tasks that a person performs. A typical flow process chart is shown in Fig. 2.

The operation process chart only addresses the introduction of material into the production cycle, and the sequence of operations and inspections subsequently performed on it. This chart is an excellent way to quickly learn what goes on and provides a superior way to explain a before (proposed improvement) and after situation to management. A sample process chart is shown in Fig. 3.

The five activities have been assigned standard symbols so that process charts would be universally understandable.

FLOW PROCESS CHART

SUBJECT ______________________________ DATE __________

____

CHART BEGINS ______________________________

CHART ENDS ______________________________

SYMBOLS	DESCRIPTION	REF	DISTANCE MOVED IN FEET	UNIT OPER TIME IN HOURS	UNIT TRANS TIME IN HOURS	UNIT INSPECT TIME IN HOURS	DELAY TIME IN HOURS	STORAGE TIME IN HOURS
○ ⇨ D □ ▽								
○ ⇨ D □ ▽								
○ ⇨ D □ ▽								
○ ⇨ D □ ▽								
○ ⇨ D □ ▽								
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○ ⇨ D □ ▽								

Fig. 2 FLOW PROCESS CHART

OPERATION PROCESS CHART

PRESENT METHOD

SUBJECT CHARTED Panel Assembly DRAWING NO. A2-496

DATE CHARTED 5-15-85 CHARTED BY J. Ruecker'

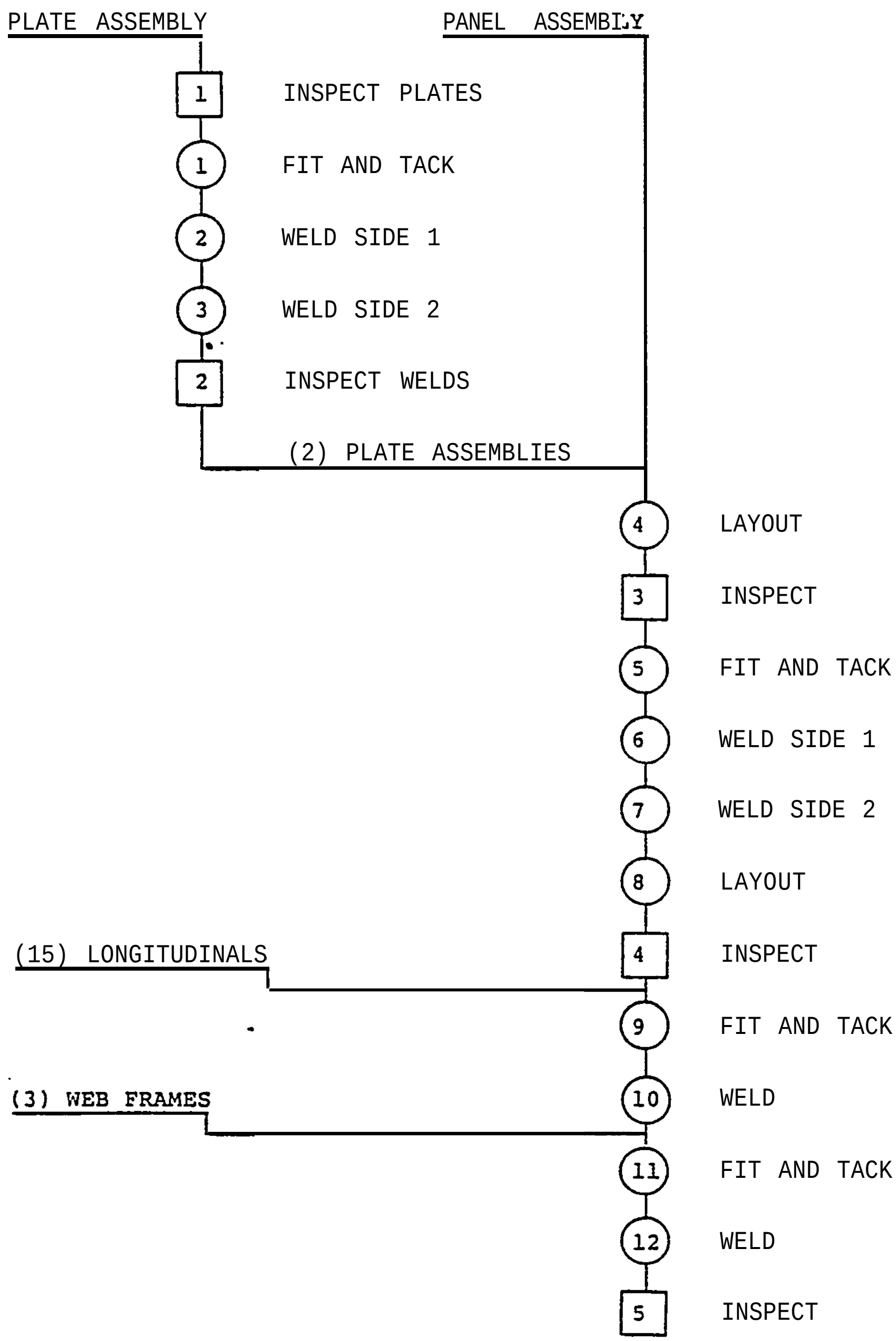

FIG. 3 TYPICAL OPERATION PROCESS CHART

Activities Defined:

Operation. An operation occurs when an object is intentionally changed in any of its physical or chemical characteristics, is assembled or disassembled from another object, or is arranged or prepared for another operation, transportation, inspection, or storage. An operation also occurs when information is given or received or when planning or calculating takes place. (Symbol: Circle)

Transportation. A transportation occurs when an object is moved or a person moves from one location to another, except when such movement is part of the operation or is caused by the operator at the work station. (Symbol: Arrow)

Inspection. An inspection occurs when an object is examined for identification or is verified for quality or quantity in any of its characteristics. (Symbol: Square)

Delay. A delay occurs when an object or person waits for the next planned action. (Symbol: D)

Storage. A storage occurs when an object is kept and protected against unauthorized removal. (Symbol: Inverted Triangle)

<u>Measure the Time of an Operation</u>

"Work measurement is the application of systematic techniques to determine the work content of a defined task and the

corresponding time required for its completion by a qualified worker". There are a number of techniques such as estimates, historical data, stop watch time studies, predetermined times, standard data and work sampling.

Estimates - is the least accurate of the techniques. Usually developed from gut feel with occasional use of factual data.

Historical Data - requires good record keeping in order to have any value. If proper record keeping is in place this techniques is valid. However, it tends to cover over poor methods, and locks in inefficient operations.

Stop Watch Time Studies - commonly used technique to establish operational time values. It is as accurate as the observer is trained in the technique. It's short coming is the observers ability to make judgement calls to correct for operator skill and effort levels.

Predetermined Times System (PTS) - are usually very structured and detailed to maintain accuracy. Their application may be time-consuming depending on the level of accuracy required, and the length of time the task takes. A number of systems are used today, each one has a specific application, primarily dependent on level of accuracy required. The systems inlcude MTM, MOST, MEK, UAS, Work Factor, etc.

Work Sampling - is an inexpensive means of getting a fairly accurate measure of machine downtime, manpower utilization, crane wait, setup time, etc. in a shipyard. Work sampling is based upon the laws of probability. A random sample from a large group tends to have the same pattern of distribution as the large group. The sample size is determined by the accuracy required and the occurrence of the task. Charts and nomographs are typically used to establish the size of the sample.

Standard Data - is a higher level of predetermined time systems. It takes the small time blocks of PTS and are combined into larger blocks of times for typical products for faster application. This is achieved by using time formulas, curves, nomographs, and charts.

Examine the Facts

Methods improvement can only be accomplished with an open mind. Do not take any method for granted, no matter how long it has been done one way or how good the present method seems. Remember there is always a better way.

The technique of work simplification, more than anything, relies on good common sense and a few logical steps. First, establish a job or function you want to improve. Look for jobs that have many delays, bottlenecks, poorly maintained machines, excessive set up time, etc.

Second, break down the job so it can be effectively analyzed. It is much easier to analyze a job when it is broken down into small elements so attention can be paid to one element at a time.

A number of tools and techniques can be used to break down a job. One very good tool is the "questioning" attitude.

"Why" is the most important question and should be asked first and then applied in turn to each of the other questions: What, Where, When, who, and How as follows:

Where should it be done? Change sequence?	Why should it be done there? Combine?
When should it be done? Change sequence?	Why should it be done then? Combine?
Who should do it? Eliminate?	Why should he do it? Change sequence?
How should it be done? New process?	Why should it be done that way? Change method?

Ask these questions so that the answer may lead to eliminating, combining, rearranging, and/or simplifying some of the activities.

Listen for comments from the workers and foremen. "Bitches", complaints, suggestions often have the gem of an idea for you to build on - and provide built-in involvement later on. This information will mostly be opinion and the facts will have to be sorted out in order to be meaningful data.

Develop the Improved Method

After the method to be studied has been selected, the gathering of facts on the current practices begins. This is the very first

step in developing the improved ‘method. You must first know how the operation is currently being performed before good solid suggestions for improvement can be made. The collection of facts will provide the data that, once analyzed, will provide the clues for improvement. During this' phase, suggestions on how to improve the operation should be solicited from the people performing and supervising the operation. The more views received on how the operation can be improved, the better the chances of success with the final proposed method. The person actually performing the work will usually have the most valuable input for improving an operation. He also can make the new method work or not work.

After the analysis has been completed and the optimum solution has been picked, develop a brief report describing the improved method. Keep it short with a minimum amount of detail. You can always go back to your files to answer detailed questions, that is, if you have done your homework. The report should start with a description of the current operation that is being considered for change. Then a description of the' proposed changes and the benefits of making such a change. Include a Comparison Chart of present versus proposed.

Selling the Improvement

Resistance to change is a major impediment to methods improvement activities 'in most organizations. As irrational as such resistance may seem at times, it does serve the purpose of testing new ideas so that they will not be accepted and implemented prematurely. Once you understand the individual and organizational obstacles

that inhibit change, you will be able to develop your creativity more fully and "sell" your ideas more successfully.

Methods improvement implementation requires cooperative effort. But many people get so ego-involved with their ideas that their suggestions for a modification are automatically opposed as unnecessary tampering. As a result, they fail to elicit the participation and cooperation of- associates during the development and implementation stages.

Presenting a new idea is in many ways one of the most crucial aspects of the methods improvement process. Here are some ways to improve your chance of success:

1. <u>Presenting to a group?</u> Try to sell it (or better still, try to involve them) before the meeting to one or more members. They'll appreciate your advance confidence and, possibly, rally to your side if the going gets rough during the presentation.

2. <u>Give background.</u> Before actually presenting the idea, give a short history of the problem which led you to investigate the area and how you proceeded to solve the problem and created the new idea.

3. <u>Show them you've thought it out.</u> Demonstrate by your conversation that this idea isn't the first one you've dreamed up. You've thought the problem out and made various approaches and refinements until you're satisfied that you have something worthwhile. You must be prepared to prove that you've thought it through. Charts and diagrams may help here.

4. <u>Don't knock the status quo.</u> Your audience may have been intimately involved in getting things running the way they do now, so don't be hypercritical of "things-as-they-are". Instead, talk about the better times ahead - if the proposed idea is accepted.

5. <u>Go slowly.</u> The presentation of new material should be delivered no faster than it can be understood and absorbed. Clear language is absolutely necessary.

6. <u>Emphasize the money angle,</u> where appropriate. When selling an idea to top management, remember that a strong dollars and cents case <u>must</u> be made.

7. <u>Sum up.</u> At the end of your presentation, sum up the outstanding points, the anticipated advantages of the idea, the need that exists or can be created for the idea, and why you think the idea should be adopted.

8. <u>Put it in writing.</u> Not everyone is capable of following an oral presentation, so stack the odds in your favor by leaving. copies of a clear, well written report with your listeners.

<u>Implementation</u>

The ground work for implementing an improvement project actually starts with selecting the work to be studied. What you do and how you do it from that point to the time you are going to make the change will determine the success of implementation. If you have:

0 Involved everyone concerned,

0 Listened to their ideas,

- Taken the time to completely understand the current method,
- Conducted a thorough analysis,
- Come up with a genuine cost-effective improvement,
- Sold the idea and answered all questions.

Then you will have all the detail and support required. If not, be ready for a rough implementation period.

In most cases when introducing a new method, the worker will require retraining. In the training the most important thing will be to develop a habit of doing the job the correct way. Habit is a valuable aid in increased productivity as it reduces the need for conscious thought. Good habits can be formed just as easily as bad ones.

Maintaining the New Method

It is important that, when a method is installed, it should be maintained in its specified form, and that workers should not be allowed to slip back into' old methods,' or introduce elements not allowed for, unless there is very good reason for doing so.

Action by the implementor is necessary to maintain the application of the new method because human nature being what it is, workers and foremen will tend to allow a drift away from the method laid down, if there is no check. If it is found that an improvement can be made in the method (and there are very few methods which cannot be improved in time, often by the operator himself), this should be officially incorporated: a new specification drawn up.

One of the most universally used techniques to insure adherence to approved methods is by use of a Labor Standards Reporting System.

Conclusion:

There is a greater need today than ever to increase productivity in the U.S. shipbuilding industry. Everyone must do their part in order to meet this goal. The techniques present will aid in uncovering areas for improvement and help establish a new improved method. The success of this approach relies on good common sense. No matter what a chart or formula tells you, if it does not make sense, it more than likely will not work or be short lived.

The application of industrial engineering techniques can be applied yard-wide. However, success will come faster if they are applied in an area you are responsible for rather than pointing out to the other guy how his area can be improved.

The application of. industrial engineering techniques, group technology, just in time, etc. can not be considered to be panaceas in themself. Production improvements will come through the application of portions of those techniques which make the most sense.

Remember; Question the current way of doing business, use good common sense in introducing change and there will be a better tomorrow.

The Reluctance to Implement New Technology: Industrial Engineering's Role

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ABSTRACT

Although the U.S. has been a leader in technological development, it has fallen behind some other countries in the industrial implementation of these new methods. Recently issues of Industrial Engineering have addressed such issues as a lack of management commitment to Computer Integrated Manufacturing Systems (CIMS)I factors limiting the growth of robotics in the U.S., and the reluctance of management to implement office automation. The paper will examine these issues and present some of the published hypotheses of why industrial management in the U.S. is reluctant to accept and apply the newer management concepts and technologies. the industrial engineers* responsibility in finding areas where new technologies will result in improvements, preparing the justification, presenting the plan to management to gain their commitment, and directing the implementation will be discussed.

INTRODUCTION

Economic indicators point to the fact that the United States is losing competitive strength in a world marketplace that is highly competitive now and will become even more so in the near future. The President's Commission on Industrial Competitiveness declares there are glaring deficiencies in America's technological capabilities, and in a large part these are due to failure to devote enough attention to the implementation of new technology into U.S. industry [I.E. 1985].

The technological advantage enjoyed by America in the 1950's and 1960's has disappeared. America's position of economic superiority is now rivaled by competitors who have matched many U.S. achievements and are moving ahead of the U.S. American economists predict slow growth in productivity for the nest decade, and if present trends continue, the American standard of living will continue to fall and the U.S. will be a good candidate to join the ranks of once dominant world powers.. To compound the problem of being forced to compete to survive in a world economy, America's relative economic strength is lower than it has been at any time since World War II [Thurow, 1984].

Targeting one area of the U.S. system as solely responsible for the current problems is to ignore the breadth of the problem. The U.S. system and its historical progression should be considered and understood before problem areas can be identified and effective solutions implemented. If U.S. products are to become more competitive through implementation of new technology, all facets that support U.S. industry, including education and government, should be properly aligned to produce competitive U.S. products.

HISTORY OF PRODUCTIVITY - U.S. AND JAPAN

The American industrial revolution occurred around the late nineteenth century, and many industrial practices of that time undercut the foundations

of American culture, including the work ethics of farming and living off of the land. Early abuses of workers included low wages, long hours, and dangerous conditions. These practices stripped workers of their basic human dignity, and employees could hardly be expected to take pride in their work when they had no pride in themselves [Wolfe, 1983].

Just after the turn of the nineteenth century, American productivity was given a boost when Frederick Taylor implemented Scientific Management, or the application of the scientific method to managerial problems. These methods represented coherent but dehumanizing attempts to organize factory work. The results of this practice were to dramatically increase productivity through 1970 [Buffa, 1984]. This was accomplished by the substitution of machine power for man power. Scientific Management helped productivity, but also set the stage for a long history of labor relations problems that are with industry today, and have contributed to long term decline in U.S. productivity [Buffa, 1984].

After 1970, several periods of recession have plagued the U.S. economy. Even though the U.S. has recovered from these recessions, overall productivity has shown no significant improvements. During the period from 1960 to 1980, the rate of increase in U.S. productivity averaged 2.7 percent. During the same period, Japan had an average productivity increase of 9.4 percent, and France and West Germany had productivity increases of 5.6 percent and 5.4 percent respectively [Buffa, 1984]. This loss of productivity is but one indication of the effects that failure to compete in technology implementation has in the U.S. economy.

Other factors that contribute to the U.S. economic decrease can be seen in the history and direction U.S. management and Japanese management have taken regarding technology.

The Japanese have historically been fierce competitors, and this is evidenced in their long history of overcoming adversity. During the rebuilding years after World War II, Japan became known as a exporter of low quality products. To solve this problem, Japanese industry focused on quality control techniques, many of which were taken from U.S. industry [Wolfe, 1983].

Japan's rising economy is relected in a real rate of growth, which is a measure based on technological advance. Japan's real growth can be measured by annual rate of increase in gross domestic product, and has been consistently above other industrialized countries [Peck and Toto, 1982]. This consistent growth and sustained leadership is a good indication of how Japan has implemented technology better than other nations in the comparison, including the U.S. [Peck and To to, 1982]. Focusing on specific areas of Japan's strategy and policy may be helpful to identify problem areas in U.S. technology and industry.

Key areas in Japanese industry that directly effect application of technology include balance of trade, research and development (R&D) spending, technology importation and wage and management systems. A larger fraction of Japan's R&D effort is funded by the private sector of their economy than most industrialized nations, including the U.S. Also, in terms of pure spending, real levels of U.S. R&D spending have declined by 2% since 1970, compared to Japan's which has increased by 17% in the same period. Japanese R&D expenditures are allocated thru competitive private sector markets, and the nature of this competition is to produce a better product, in contrast to U.S. R&D spending which is mostly funded by the federal government (and unimproved by lack of competition). In Japan, the risk inherent in expensive R&D efforts is also eased by Business Groups, or groups of companies that have valuable technology distributed among them, and the risks are distributed as well.

Japan is uniquely suited to take advantage of imported technology with a highly skilled and flexible labor force, a good supply of managers, scientists, and engineers, and the ability to implement technology to their advantage. Through imported technology, Japan avoids the high risk and cost of initial development [Peck & Goto, 1982].

The steel industry provides a good example-of how Japan seized upon the latest technology and why the U.S. is having economic problems. Even though established U.S. producers of steel had much greater experience than the Japanese and Germans, and should have been unbeatable on a cost basis, approximately 200 U.S. steel firms have closed. A large portion of U.S. steel is made in open hearth furnaces. This differs from Japan and Europe, where they use primarily oxygen and electric furnaces (much improved over open hearth). U.S. steel makers have neglected to convert to continuous casting as the Japanese and Europeans have done. These processes improve product yield, cut energy use, and increase labor productivity. Twenty-six percent of U.S. steel is continuously cast, versus 86 percent in Japan and 61 percent in Europe. A clear disadvantage for the U.S. [Buffa, 1984] and questions arise as to why. This can be answered in the context of labor, management, government, and social structure differences.

CURRENT U.S. PRODUCTIVITY AND ECONOMIC EFFECTS

The U.S. no longer has a self sufficient economy where labor, management, and government can abuse each other and not feel the effects rather quickly. The U.S. is being forced to compete in world markets, and this open trade will not support the costs of inefficient productivity. As evidence, total imported goods now account for 19 percent of U.S. consumption, up from 9 percent in 1970. The U.S. imports 28 percent of its cars, 18 percent of its steel, 55 percent of its consumer electronics products, and 27 percent of its

machine tools. Japan was the first country to challenge U.S. products, and now countries such as South Korea, Taiwan, and Singapore are beginning to impose on U.S. markets [Alexander, 1483].

Differential labor rates are a prime reason for imports. For example, average labor rates are less than two dollars in South Korea and Taiwan, compared to $7.53 in the U.S. (May 1983) [Alexander, 1983]. Why are U.S. workers paid more, yet productivity is lower? According to James Harbour, auto consultant in Detroit, a good example is that better factory layouts and more flexible use of workers enables Japanese automakers to assemble a car in 15 man hours versus 30 man hours in the U.S. [Buffa, 1984].The blame here seems to belong to American management.

To further emphasize that U.S. manufacturing and management are to blame for the lack of technology implementation, consider foreign cars produced in the U.S. These cars typically have manufacturing costs two thousand dollars higher than their foreign counterparts. Due to the inefficient technology used in production, these situations are typical of how American industry is being forced to, catch up with world industries [Buffa, 1984].

Over the past several decades, U.S. management has shifted its focus from the production function to a marketing and finance orientation. During and just after World War 11, and U.S. had no rivals in manufacturing capability and productivity. Due to this lack of global competition, American manufacturers put increasingly more emphasis on business functions and less on productivity. The marketing era produced unparalleled levels of sales in the U.S., and the finance era followed as firms began to manipulate their newly acquired wealth during the 1970's. The concepts of mergers and acquisitions were introduced during this period, and should bear much of the blame for effects of inefficient financing and poor management. The problems with

"merger mania" are described in a quote by Reich, "...paper entreprenurialism has replaced product entrepreneuralism as the most dynamic and innovative occupation in the American Economy. Paper entrepreneurs produce nothing of tangible use. For an economy to maintain its health, entrepreneurial rewards should flow primarily to products, not paper." [Buffa, 1984]. Mergers often result in no net addition of economic output for corporations, and millions of dollars in stockholder's funds may be spent. Certainly the time and money spent could better be used on productivity improvements and technology.

Another area of consideration is U.S. government action and policy, and the effects these have on the American economy. Since the early 1960's, there have been extreme differences between Capital Hill and the business/industrial community. Much public respect and support has been robbed from large industry, evident in the sentiment that business was corrupt, crooked, and colluding to rob the public. U.S. government's answer to these problems was anti-trust legislation. The long term effects of these policies are an atmosphere of non-competition and inhibitions against corporate joint ventures. The world is a competitive arena, and these restrictions have handicapped U.S. industry [Manufacturing Engineering, 1985].

Some government policy is blamed for adversely affecting productivity for the sake of improvements in air quality, noise levels, and employee safety. However, the U.S. can claim no disadvantage here compared to European and Japanese steel makers who spend as much or more on pollution and safety equipment. Gaining a better perspective, capital expenditures in most U.S. industries for pollution and safety combined can be blamed for at most around one tenth of the slowdown in productivity [Buffa, 1984]. The blame once again comes to rest on U.S. manufacturers.

American management's short term mentality and refusal to accept its fair

share of the blame have sent many traditional "smokestack" industries into decline. Industries such as autos, steel, rubber and shipbuilding that were once synonymous with American industrial power have rapidly declined. As evidence, 19 percent of industry's blue collar work force are on indefinite layoff. Even as many old line industries decline, new technology is creating many opportunities in fields such as microelectronics, lasers, fiber optics, and genetic engineering [Alexander, 1983]. While new technology creates work, it also destroys many jobs in outdated industries. It is also possible that new technology, if improperly implemented and mishandled as past technology has been, will not provide the foundation of economic recovery that is hoped for, and may even contribute to U.S. economic decline.

SOLUTIONS AND FUTURE DIRECTIONS

Most of the initial effort aimed at solving U.S. productivity problems is reflected in the American affinity for quick, easy, short term solutions to problems that require extended treatment. Application of Japanese management to American industry may not necessarily be the answer. The Japanese forte appears to be successful management of people. This has been achieved by successfully evaluating the best of other cultures within the context of their own social structure. Japanese philosophy is reflected in their cultural cohesion and commitment to common goals [Wolfe, 1983]. America does not have the level of cultural cohesion or commitment to common goals exhibited by Japan, and blind application of Japanese techniques by U.S., industry may plunge U.S. productivity into a worse position.

Careful consideration must be given to how new technology should be applied in the U.S., where labor is in surplus, as opposed to Japan with a labor shortage. American firms must take a hard look at the role of the work force in productivity. Specific areas of Japanese worker-industry relations

that may be transferable include long term commitments to employment, simplified labor relations, and flexibility of work rules that allow workers to perform a wide variety of tasks, towards achievement of more efficient use of labor [Buffa, 1984].

Reich challenges the idea that flexible production systems in use by many of America's competitors can be successfully implemented into America's high volume, standardized industrial base, since most large U.S. enterprises are too fragmented and bureaucratic to accommodate the novel techniques used abroad [Wolfe, 1983].

The plea for protection of U.S. industry by Federal legislation is yet another example of how American firms pass on their share of responsibility for economic recovery. Since many U.S. products cannot compete with foreign products in a free market, the U.S. government is asked to remove the competition. Import quotas on cars, motorcycles, steel, textiles, and other products represent the protection, but these policies may backfire on the U.S. through slowed rates of foreign debt repayment by other countries. Also, the U.S. has become more dependent on world markets during the past decade, and these products could be a prime target for foreign competitors in cases of protectionism or trade wars [Alexander, 1983]. Protectionism also serves to directly drain the internal U.S. economy. An example is the steel industry. Shielding from foreign competition has allowed the industry to defer plant modification through new technology. The result is that U.S. steel industry has allowed its production facilities to become outmoded, and inefficient production can inhibit economic recovery.

Another proposed solution is a National Industrial Policy similar to Japan's. MIT economist Lester Thurow argues that these schemes would not be very effective. This strategy involves targeting government aid for new

and promising firms. Thurow argues that the Japanese system has always had government aid, as opposed to the American economy based on individualism and entrepreneurialism. U.S. money would be better spent on massive retraining efforts required by high tech industry and improved science and engineering education programs [Thurow, 1984].

The educational system of the U.S. may have been one of the earliest contributors to America's current technological problems. According to Anderson [Anderson, 1983], Japan has a higher percentage of students enrolled in engineering courses. In Japan, approximately 20 percent of all bachelor degrees are in engineering, compared to 5 percent in the U.S. The total number of scientists and engineers increased by 62 percent in Japan between 1968 and 1978; the U.S. had a 13 percent decrease during the same period. The Soviet Union is also rivaling the U.S. in technical education [Anderson, 1983].

Addressing the needs of the American educational system in the area of science and math is a first step towards rebuilding a foundation for implementing future technologies. Instilling students with interest in science and engineering, and providing quality education at all levels must take place through action and funding by business, industrial, and public sectors at the American economy. By contrast with our foreign competitors, the U.S. government has no clear and coordinated national policy for development of future scientists and engineers. Japan and other industrial powers have had such a policy for several years [Anderson, 1983].

AUTOMATION AND NEW MANAGEMENT

U.S. management must lead the way in the reform of management philosophy toward better productivity through implementation of technology. This can be accomplished through new emphasis on manufacturing functions and new technologies that contribute to-productivity and quality improvement.

According the Anderson, America may be forced to rely more heavily on automation and other new technologies, if it hopes to operate as efficiently as foreign industries. For example, if Ford Motor Company were to continue operation with current technologies and become as efficient as Japanese auto industry, it would need to cut its work force of 256,000 employees in half [Anderson, 1983]. Plant automation requires large capital investments, product volumes to justify financial outlay, and heightened employee involvement and education, to name just a few requirements to make technology implementation in industry a success [Manufacturing Engineering, 1985].

To complement increased automation, U.S. manufacturers need to restrict their interest to basic product lines and concentrate on doing fewer things well. In a comprehensive study, Rumelt found that companies that stick to their basic core business consistently outperform those that spread their resources too far [Buffa, 1984]. Diversification should be restricted to businesses that share close relationships.

Change in the philosophy of U.S. production management is needed, but can be effective only if supported from the top of the organization. According to Buffa, Japanese management structure provides a good yardstick for U.S. industry. More than 65 percent of all seats on boards of Japanese manufacturing companies are occupied by people who are trained as engineers. Almost the same percentage of seats on American boards are taken by people trained in law, finance, or accounting.

In Japan many problems that arise in industry are viewed as problems of engineering or science with technical solutions. American business problems are likely to be viewed as problems of law or finance to be dodged (not solved) through clever manipulation of rules and numbers. This results in a failure of managerial competence as evidenced by poor manufacturing strategy

and productivity [Buffa, 1984].

CONCLUSIONS

Several decades ago the United States did not truly believe that Japan or Germany could make automobiles, tractors, and machine tools as well as America could. U.S. industry "rested on its laurels" and did not push to improve productivity or maintain a quality image. As a result., the U.S. is currently behind foreign competition in the implementation of new technologies and automation. Efficiently produced foreign products have penetrated and captured large shares of U.S. markets, and the result has been a weakened U.S. economy. America's industrial and technological inferiority has implications relative to our living standards, education, and defense; really at the center of our national well being.

Effective solutions cannot be borrowed from Japan, but must come from the industrial heart of America where the problems had their beginnings. The mismanagement of U.S. firms must be resolved, or foreign competitors will continue to have the advantage. If current trends are any indication of the future, high productivity as a result of technology implementation will be even more critical to the economic survival of the U.S. in a world market.

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IMPROVING SHIPYARD PRODUCTIVITY THROUGH THE COMBINED USE OF PROCESS ENGINEERING AND INDUSTRIAL ENGINEERING METHODS ANALYSES TECHNIQUES

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ABSTRACT

Despite the obvious compromises to efficiency that must be made when producing small quantities, the shipbuilding industry sometimes rules out or fails to consider some of the efficient techniques and methodologies of mass production manufacturing.

In this paper a comparison and contrast is made between the methods of mass production and small quantity manufacturing. Also revealed in this paper are the benefits from the use of a mass production process engineering technique and a methods analysis technique during the performance of the National Shipbuilding Research Program's SP-8 panel Task E-8-21. The use of a mass production process engineering technique (using tool routings to provide a summary of all of the tools, gages, etc. required to operate and control the products being produced from mass production machining and assembly equipment) is explained as a solution to a methods problem of excessive travel for tools in shipboard equipment machining and installation by Outside Machinists. The paper concludes with a promotion of this specific application of mass production methodology in shipbuilding and a promotion of the re-evaluation of mass production techniques by shipyards as a vehicle for productivity improvement.

Improving Shipyard Productivity Through Process Engineering And Industrial Engineering Techniques

INTRODUCTION

There is growing concern in the U. S. shipbuilding industry about productivity. This concern is caused by the inability of U. S. shipyards to compete with foreign shipbuilders in the market for construction of commercial ships and by the decline in U. S. Naval ship construction contracts over recent years. Both of these problems put many U. S. shipyards in a position of literally fighting for existence. In an effort to increase productivity, the U. S. shipbuilding industry has, for example, made improvements to shop facilities, investigated the use of robotics, re-evaluated support labor requirements, and utilized CAD/CAM computer Aided Design/Computer Aided Manufacturing) technology. All of these activities are worthwhile endeavors. However, most of these productivity programs have little or no impact upon onboard ship construction. Not enough is being done oh a consistent basis to improve the productivity of the machinist, pipefitter, welder etc. who is working on the ship.

The U. S. shipbuilding industry needs to make a re-evaluation of the entire current system of basic ship construction being employed in America. Even the Japanese shipbuilding techniques, which have been investigated by U. S. shipbuilders, are actually sound principles of industrial engineering methods analysis as applied to shipboard work.

The principles of methods analysis have worked well over the years as a labor cost reduction tool in the mass production environment. However, the traditional mass production principles of industrial engineering methods analysis need creative adaptation to obtain productivity improvements in the onboard ship environment.

MASS PRODUCTION VERSUS SMALL QUANTITY MANUFACTURING

The basic difference between mass production and small quantity manufacturing is the number of units produced during a given time frame. In mass production, a large number of identical units are manufactured over a relatively short time frame. An obvious example of mass production is the manufacture of a popular American automobile model whose volume would exceed one million units per year. The mass production repetition has two important advantages. First, a worker quickly reaches the point on the learning curve where virtually no more learning can occur. Thus, the unit cost is at its lowest possible point. Secondly, it becomes feasible to perform a detailed method analysis on each direct labor function to uncover any inefficiencies in the production methods and to foster productivity improvement in mass production.

In small quantity manufacturing, a small number of identical units are manufactured over a relatively long time frame. An example of this would be the manufacture of ten ships over a five year period. The lack of repetition in small quantity manufacturing has two major disadvantages in the area of efficiency. First, a worker never reaches the point on the learning curve where no more learning can occur. Thus, the unit labor

cost is very high when compared to mass production. Secondly, in small quantity manufacturing, the performance of detailed methods analysis of each labor function is not as feasible as it is in mass production. However, this article will present evidence to prove that proper application of methods analysis techniques can be quite advantageous, even in the construction environment onboard a ship.

EXAMPLE: A TOOL LIST PROGRAM

Background

In December of 1983, Ingalls Shipbuilding began to perform the National Shipbuilding Research Program (NSRP) Task ES-8-21, the Data Development of Detail Standards for Outside Machinery Operations. During this project, time standards were developed for outside machinery equipment installation using the Maynard Operation Sequence Technique (MOST), a predetermined motion time system. The purpose of this project was twofold. It was primarily to provide the shipbuilding industry with a set of universal standards for outside machinery operations. It was also to identify specific areas where methods improvements could be made to benefit both Ingalls Shipbuilding and the U. S. shipbuilding industry.

During the shipyard observations by methods analysts, the problem of excessive travel for tools by outside machinists became apparent. Methods analysts discovered that some machinists were reporting to shipboard job sites without all of the tools required to perform the job. Numerous trips were made off of the ship for additional tools. Further analysis revealed that correction of the problem would save Ingalls Shipbuilding

over $300,000 annually in direct labor cost for excessive travel alone. Communications with other shipyards through NSRP SP-8 Panel on Industrial Engineering revealed that the problem was industry wide.

Realizing that the problem was industry wide, Ingalls Shipbuilding submitted a proposal that was approved by the SP-8 Panel to implement and evaluate a solution to this problem. The proposed solution was to provide machinists with tool lists that would enumerate all of the necessary tools required to perform each job. The idea for this proposed solution was extracted from the mass production process engineering technique of using routing sheets. The routing sheet is used to list the machines or tooling required to produce a part.'

Program Advantages

This tool list program's primary objective and major emphasis is on the elimination of excessive travel to obtain tools by outside machinists. However, the benefits of this program are not limited solely to reduction in excessive travel for tools. There are additional benefits that can be obtained from a tool list program. The following is a list of these additional benefits.

1. A comprehensive list of the tools required to perform specific tasks can be provided as a training aid for apprentice machinists.
2. By providing a comprehensive list of tools required to perform a task, a tool list program reduces the amount of time an experienced machinist would have to spend planning the performance of a task.

3. If the tool lists are stored in a computer, the tool list program can provide tool room personnel with a schedule and detail listing of the tools required during a given time frame. The list can assist in forecasting tool requirements with accuracy.

<u>Application</u>

The outside machinist supervisor is the backbone of a tool list program. Without his cooperation a tool list program will not be worth the paper the fool lists are printed on. The supervisor must encourage and monitor the use of the tool list program by his employees. if he does not, the chief objective of the program will not be realized--the elimination of excessive travel. Therefore, to insure the success of a tool list program, the supervisor's participation in the program from its inception is essential. Ideally, the supervisor should be able to feel that it is his program even if it was not originally his idea.

> IT has been said that the perfect staff work can be identified easily because the recipient of the staff work finds it difficult to identify the role of the staff helper and differentiate it from his own role in the solution of the problem....[2]

One way to get the supervisor' to participate in the program is to have him develop the tool lists. This way the tool list becomes his own work and, thus, he will become its greatest proponent.

If the supervisor is too preoccupied to develop detailed tool lists, someone else should develop them and the supervisor should review them for accuracy.

The next steps are to determine which areas of the shipyard to use the tool list concept and if the program is economically feasible for a given ship construction contract. The most obvious place to start using a tool list program is with shipboard equipment installation utilizing the ship series production concept. Series production is defined as the production of a series of nearly identical ships.[3]

In the case of series production, once the tool lists have been developed, only the minimal cost of maintaining the tool list program is incurred after the first ship. To determine economic feasibility of a tool list program, an evaluation of the associated administrative costs and cost savings must be made. In the proceeding analysis, the payback period Will be used to make the evaluation of a typical program's economic feasibility.

Payback Analysis

The details of a payback analysis based on information obtained from an actual tool list pilot program implemented at Ingalls Shipbuilding is shown in Tables 1 and 2.[4] This particular tool list program involved the construction of Ticonderoga (CG-47) Class cruisers built in series. The administrative costs are shown in Table 1. Also shown in Table 1 are the organizations involved within the company and the scope of their activities as they relate to the tool list program.

TABLE I - TOOL LIST PROGRAM

ADMINISTRATIVE COST

ADMINISTRATIVE IMPLEMENTATION COST	
- COMPUTER SERVICES (Computer Usage)	$ 1,035
INDUSTRIAL ENGINEERING (Coordination and Tool List Development)	76,125
OUTSIDE MACHINERY (Review Tool List Development)	8,760
TOTAL	$85,920
ANNUAL ADMINISTRATIVE OPERATING COST	
COMPUTER SERVICES (Computer Usage)	$ 1,421
OUTSIDE MACHINERY (Changes and New Equipment)	876
PRODUCTION PLANNING (Tool List Added to BOM)	7,597
REPROGRAPHIC SERVICES (Additional Paper Generated)	165
TOTAL	$10,059

Table 2 shows the payback period calculation. The annual operating cost is subtracted from the gross annual savings to yield a net annual savings. The implementation administrative costs are considered as an investment cost which is divided into the gross annual savings to yield a payback period of 27 years.

Although the feasibility of the tool list concept must be evaluated based on the particulars of each shipyard's product mix, this basic thesis has been proven by this example: the tool list concept is economically advantageous for nearly identical ships built in series.

Program Description

This tool list program was designed to provide the maximum amount of information to the craftsman with the intention of holding the administrative cost of the program to a minimum. The highlight of this program is that the tool list is printed on the bill of material kitting report. Use of this system provides a complete summary of both tools and materials required to complete a given job. The mechanics of this program and the departments involved are shown in Figure 1.[5] First, an industrial engineer develops the tool lists and an outside machinery supervisor reviews them for accuracy. An industrial engineer then stores the tool list in the Technical information Data Base (TIDB) Text System. The industrial engineer also develops an Account and item to Tool List Code Matrix to identify the location of each tool list in the computer as shown in Table 3. The planner then uses the matrix to match each major piece of equipment on a bill of material kitting report to a tool list code number. The tool list code number, kitting report number, and hull

TABLE 2

TOOL LIST PROGRAM PAYBACK ANALYSIS

Gross Annual Savings	$323,651
Less Annual Administrative Operating Cost	-10,059
Net Annual Savings	313,592
INVESTMENT (Administrative Implementation Cost)	$85,920
PAYBACK PERIOD	0.27 YEARS

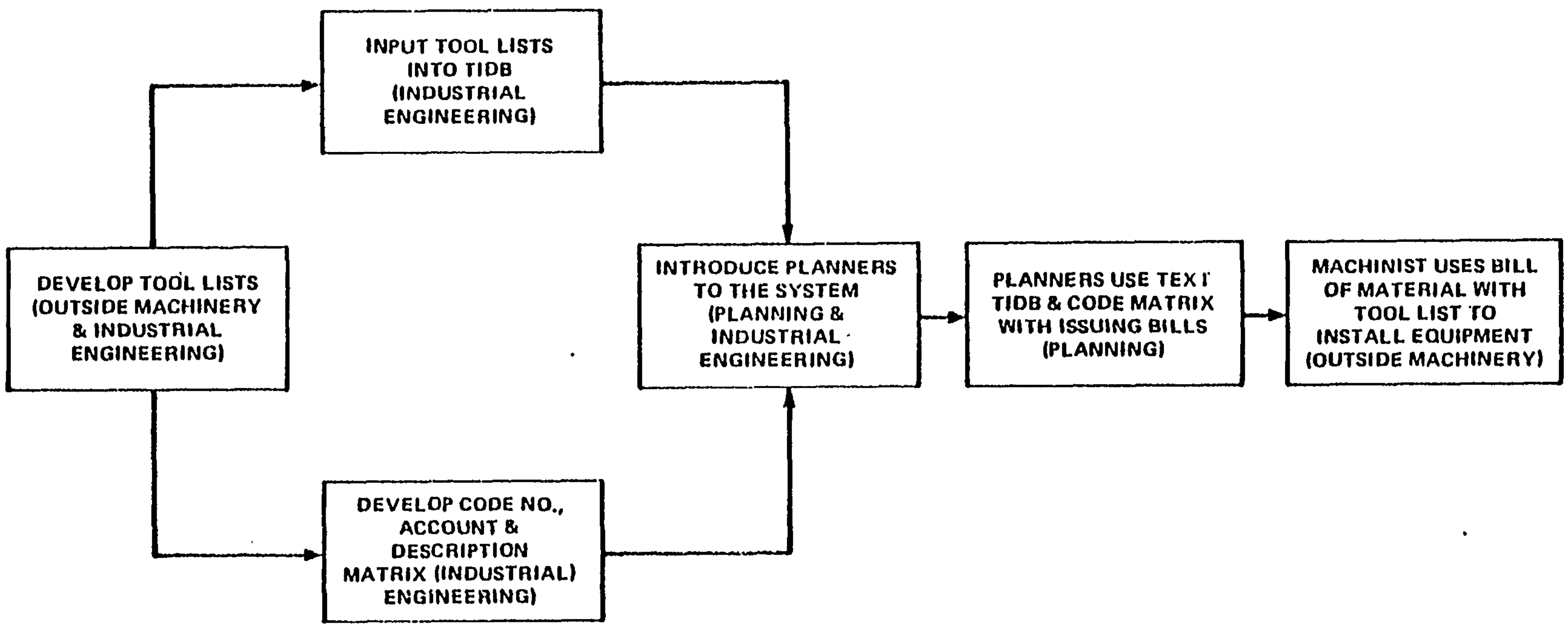

FIGURE 1 TOOL LIST PROGRAM NETWORK DIAGRAM

TABLE3- SAMPLE ACCOUNT AND ITEM TO TOOL LIST CODE NO. MATRIX

ACCOUNT NO.	ITEM DESCRIPTION	TOOL LIST CODE NO.
2501'	BELLMOUTH	0100
2501	COOLING COIL	0101
2501	PRECIPITATOR	0102
2501	FAN COIL ASSEMBLY	0103
2.501	POWER PACK	0108
2.501	TOXIC GAS DAMPER	0107

identification number is typed into the TIDB Text System by the planner. The computer then generates a bill of material kitting report with a tool list attached as shown in Figure 2. Now the machinist can gather all of the necessary tools and materials to complete a job by referring to one document.

THE COMPUTER INTERFACE

The computer interface is with the TIDB Text System. The TIDB Text System is a computer program written by Ingalls Shipbuilding Information Systems Department for the express purpose of adding notes to the bill of material kitting report. These notes provide supervisors and workers with information that would assist them in ship construction. The five available options of the TIDB Text System are as shown in Figure 3. Option number one allows tool list data to be input, changed, or removed from the computer; thus, the actions create/modify/delete. The tool list data was input into the computer under a dummy bill of material kitting report number **(0000-000-1)** and a dummy bill hull,identification number (4500). The second option, Detail Text View, allows the data that has been input from option number one to be viewed. Option number three, Merge paragraph from existing bill, allows the tool list information stored on the "dummy" bill of material kitting report to be transferred to the bill of material kitting report that the tool list data is-applicable to. Option number four, Bill Paragraph List, displays the paragraph numbers (tool list code numbers) on any given bill of material kitting report. Option "X" allows one to end the session of interaction on the program.

```
                         BILL REV:                      INGALLS SHIPBUILDING      MATL CODE: ___      CHANGE REASON: ________
DATE: 03/28/85 02:40  BILL: 2501-236-1   HULL: 4504  DESC: VEHE EQUIP MOD 4 ASSY 404                    REPORT NO. : X83352-R1
DEPT: P P & S         REQD-DT: 091084   DISIR: N       KITTING REPORT            BILL PAGE NO:    1       RPT PAGE NO:      693
SCHED ISS: 081384 ACT ISS: 073084 LATEST CHG: 000                          'LEAD DP: 24 ASSIST DP: 77      WORK STA NO: 590

                                                                                       **************************
                                                                                       * PLANNER: ___________   *
                                                                                       *                        *
                                                                                       *    DATE: - / / -       *
                                                                                       *                        *
                                                                                       *COMPLETE:    Y,    N-   *
                                                                                       **************************

          PARA        <<< ------------------ TEXT ------------_---------- >>>

          0104        ************************************************************************
                      *                       OUTSIDE MACHINERY                                *
                      *                     VENTILATION EQUIPMENT                              *
                      *                         TOOL LISTING                                   *
                      *                                                                        *
                      * DESCRIPTION:       FAN COIL UNIT                                       *
                      *                                                                        *
                      * SPECIFICATIONS:  MODEL          H1-H8 & V7                             *
                      *                    HEIGHT         265-805 LBS.                         *
                      *                    FDN BOLT SIZE    5/8 IN.                            *
                      *                                                                        *
                      *                                                                        *
                      * (A) TOOLS REQUIRED FOR INSTALLATION WHEN LINERS AREN'T                 *
                      *      NECESSARY INCLUDE:                                                *
                      *                                                                        *
                      *      BALL PEIN HAMMER    DRILL  BITS(21/32  IN).                       *
                      *      CENTER PUNCH        PORTABLE DRILL MOTOR                          *
                      *      SCRIBER             RATCHET?(1/2IN.DRIVE)                         *
                      *      8' STEEL TAPE       EXTENSION 1/2 IN. DRIVE)                      *
                      *      6" STEEL SCALE      SOCKET(15/16IN.)                              *
                      *      MOLYCOTE COMPOUND COMBINATION WRENCH(15/16IN.)                    *
                      *      C-CLAMP             PRE-MANUFACTURED TEMPLATE                     *
                      *      CUTTING FLUID                                                     *
                      *                                                                        *
                      *                                                                        *
                      * (B) TOOLS REQUIRED FOR INSTALLATION WHEN LINERS ARE                    *
                      *      NECESSARY INCLUDE                                                 *
                      *                                                                        *
                      *      ALL ITEMS  LISTED UNDER (A)                                       *
                      *      FILE                                                              *
                      *      FEELER GAGE                                                       *
                      ************************************************************************
```

FIGURE 2 PRINTED TOOL LIST ON A BILL OF MATERIAL FORM

```
*******************************************************************************
* --- TIDB TEXT SYSTEM ---    DB81ING       DATE: 04/15/85    TIME: 13:45:18   *
*******************************************************************************
              BILL NUMBER: 0000-000-1      HULL: 4500
             SELECT OPTION: 1            ACTION: C
AVAILABLE OPTIONS:
        1. TEXT CREATE/MODIFY/DELETE
        2. DETAIL TEXT VIEW  ================>         TO
        3. MERGE PARAGRAPH FROM EXISTING BILL
        4. BILL PARAGRAPH LIST
        X. EXIT
AVAILABLE ACTIONS:      C.  CREATE     M.  MODIFY     D.  DELETE
     STATUS: 033-*** PLEASE ENTER THE REQUIRED INFORMATION ***
```

FIGURE 3 TIDB TEXT SYSTEM OPTIONS

CONCLUSION

In the environment of increasing competition, the U. S. shipbuilding industry must increase productivity in every phase of its operation. in its attempt to do this, the U. S. shipbuilding industry must include the industrial engineering techniques of methods analysis as a tool to reduce labor costs in the area of onboard ship construction.

The techniques of Methods analysis have been a proven producer of productivity improvement in the mass production environment over the years. This article has provided an actual application of this in the shipboard environment. Thus, shipyards should consider actively employing methods analysis with increased emphasis in onboard ship construction work on a continuing basis.

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5. Ibid p. 9

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8. Ibid p. 11

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FIGURES

PANEL SP-9

EDUCATION AND TRAINING

Howard M. Bunch
University of Michigan

Chairman

SP-9 OVERVIEW

'In 1981 the Ship Production Committee established the Education and Training Panel (SP-9). The panel's purpose is to develop and maintain educational programs in: (1) skilled trades training, (2) pre-entry professional training, and (3) middle management training.

In the lobby there is a short S-minute video tape describing the activities of the panel. I encourage you to take a few moments and watch it through a loop.

Since inception, the panel has supported 24 projects. While all have been important, time does not permit my describing each in detail. I'd like to mention several, almost at random, to indicate the scope of the panel's interest.

First, there is this symposium, the one you're attending. The SP-9 panel was given the responsibility of organizing and administering the meeting.

The Journal of Ship Production,' an archival journal focusing on the science of ship production, was established; the costs of start-up have been underwritten by SP-9. The journal provides a mechanism for presentation of technical papers by academia and industry professionals. Such a forum is seen as a necessary ingredient in the acceptance of ship production engineering as a fully qualified professional discipline.

We prepare microfiche of all NSRP publications (including an index), and distribute them free of charge to about 50 designated shipyards and libraries around the United States. A nominal charge is assessed for anyone beyond the designated 50. The library is updated annually.

We have just launched a project that will assess the communication requirements and communication skills of shipyard workers, then develop methods to improve those skills. Professor J.C. Mathes of the University of Michigan is project director.

The panel maintains the AVMAST library and lending service of audio-visual material for shipyard training. The material is loaned to shipyards and others for use in training and educational programs.

Another program, just underway, is to prepare a lecture course on basic naval architecture. The course, with 44 distinct lectures, will have companion workbook and instructor's manual.

Today, you are going to hear indepth presentations of those projects supported by SP-9. The first describes a recently completed activity. The second will cover a project that is complete, except for the final report...so you're getting a preview. The third will tell you about an exciting program that will get underway in the next several months.

EVALUATION OF TWO MULTI-SHIPYARD COOPERATIVE TRAINING PROGRAMS

BY

Dr. Alvin J. Abrams
Data Design Laboratory
Vice President, Training

ABSTRACT

Descriptive and evaluative information is reported on two multi-shipyard training programs: (1) Tidewater Maritime Training Institute, Norfolk, Virginia, and (2) Cooperative Apprentice Training Program, Seattle, Washington. The programs differ greatly in origin, goals, organization and operation; yet both successfully met local requirements.

Both programs are described relative to their: (1) program history, (2) legal basis, (3) objectives, (4) funding, (5) geographic area, (6) staff and facilities, (7) trainee input, (8) curriculum, and (9) hiring and retention of graduates. The detailed descriptions are presented for two reasons. First, a useful evaluation must be based upon knowledge of specifics. Second, one goal of this project is to provide guidance to shipyards in other locations.

The dissimilarity between these programs is instructive. First, training for both unskilled and skilled workers can be addressed via cooperative efforts. Second, cooperative efforts may involve various relationships between federal, state and' local governments as well as between shipyards, unions, and educational institutions.

INTRODUCTION

This project was funded by the SNAME Ship Production Committee Education Panel. Data-Design Laboratories performed the work during the summer of 1984 under subcontract to the University of Michigan Transportation Research Institute. The project is described in detail as SP-9 Panel Report.[1] Three purposes stated in the Request for Proposal were:

(1) to investigate and evaluate two existing cooperative shipyard training programs,
(2) to identify other geographic areas in the U.S. where similar programs might be feasible, and
(3) to produce a program development and implementation guide for new projects.

Two programs were designated for study. These were the Tidewater Maritime Training Institute, Norfolk, Virginia, and the Cooperative Apprentice Training Program, Seattle, Washington.

Most of the information that I am reporting was obtained from interviews using four questionnaires. These questionnaires were designed to elicit both descriptive and evaluative data from four major categories of program participants: (1) program managers, (2) participating employers, (3) students and program graduates, and (4) instructors. The questionnaires were administered at both Norfolk and Seattle, and overall we found two very different but successful programs. Unfortunately during late 1984 there was little need for shipyard apprentices in the Seattle area.

"Evaluation of two Multi-Shipyard Cooperative Training Programs"
The Maritime Systems Division Transportation Research Institute,
The University of Michigan, Ann Arbor, Michigan 48109

Employment in shipyards had shrunk over 50% in the previous two years. As a result, that program was not flourishing at the time of the survey.

In addressing the questions of potential areas for shipyards, Data-Design Laboratories obtained information on 27 areas which had significant ship building and/or ship repair yards. The areas were ranked relative to total tonnage and described on four other variables that might be considered in assessing potential for a cooperative training program.

Finally, guidelines for establishing other programs were derived from what we observed in the Norfolk and Seattle programs'. Although the programs differ greatly, there are underlying principles and concepts that may be generalized.

Before going into greater detail, I would like to note that I am not certain of the rationale behind the selection of these two programs. However, they provided an interesting and informative contrast. As you will see both are well developed programs, but each meets a unique need in a unique manner. Perhaps the only commonalities are that: (1) the shipyards involved in each program defined their training needs, and (2) they meet these needs through cooperative relationships with a variety of governmental and private entities. As we look more closely at each program, we will focus on nine factors: (1) objectives, (2) geographic area, (3) program history, (4) legal basis, (5) funding, (6) staff and facilities, (7) trainee input, (8) curriculum, and (9) hiring-and retention of graduates.

THE TIDEWATER MARITIME TRAINING INSTITUTE

Objectives

First we will look at the Tidewater Maritime Training Institute. It's objectives are consistent with both local needs and the Federal Jobs Training and Partnerships Act of 1982. The program seeks to take unskilled trainee input and produce individuals who (1) are motivated to learn and to work, (2) understand the rigors of the ship repair work environment, (3) are familiar with a number of ship repair skills involving the use of tools and equipment, and (4) have sufficient mastery of basic math, blueprint reading, and safety practice to enable entry into the ship repair industry.

Geographic Description

The Tidewater area is the 31st largest Metropolitan Statistical Area in the country. Six cities in this area have a combined population of over one million people. These cities are: Norfolk (267,000), Virginia Beach (262,000), Newport News (145,000), Hampton (123,000), Chesapeake (114,000) and Portsmouth (105,000). There is considerable commercial and military maritime activity in the area. There are three major shipyards and over a dozen smaller yards. Only one of the larger yards participates in the program.

Program History

In 1972 a ship repair executive recognized the need for training entry personnel for the ship repair business. He spent a few years attempting to build the program. In late 1981, the Maritime Training Institute came into being with over a dozen ship repair companies cooperating in the venture. Federal funds were obtained from the

Comprehensive Employment Training Act (CETA). The CETA funds were complemented by donated spare materials and instructional personnel from members of the institute. CETA funding ended with the demise of CETA; however, federal support has continued through the Federal Jobs Training Partnership Act.

Legal Basis

The Tidewater Maritime Training Institute is a non-profit educational foundation, whose purpose is to operate a training facility for the ship repair industry in the Tidewater area. The parent corporation is the South Tidewater Association of Ship Repairers, whose membership includes 42 companies or corporations that are involved in the ship repair industry. There are separate boards of directors for the Ship Repairers' Association and the Tidewater Maritime Training Institute, but all directors are appointed from the associated companies.

Funding

This program has been federally funded since the inception of the Training Center. The funding level has been approximately $300,000 annually since 1981. This represents an average cost of $2,160 per student. Financial support of an "in kind" nature is provided by members of the Ship Repairers Association. This support is in the form of: (1) providing the Training Center building for $1/year, (2) providing surplus tools and equipments, (3) providing training materials such as pipe, welding rods, (4) assigning supervisors/foremen to participate in instruction, (5) providing organized tours of repair yards, and (6) involving of shipyard owners and senior executives in trainee orientation and graduation ceremonies.

Staff and Facilities

The five person staff includes an executive director, who also instructs, three instructors, and an administrative assistant. At the time of this survey, the training center was housed in an old, renovated shipyard building that was centrally located relative to the association's various shipyards. The 20,000 square foot building was divided into work areas for the various trades as well as a classroom, office space, a tool room, a conference room and locker room facilities. There were plans to relocate during the current calendar year. Within this facility, the staff administered four 12-week courses per year, with approximately 30 students per course.

Trainee Input

Applicants are obtained from responses to newspaper ads which briefly describe the course, the program, and application procedures. From 200 to 350 applications have been received for each class of thirty. The structured, multistage screening process which is employed includes review of applications, interviews, achievement testing, and physical examinations. Applicants must be eligible under the Job Training Partnership Act.

Curriculum

The training course is organized into five 8-hour days for 12 weeks. Each morning is devoted to classroom instruction, and ship work practice in each of nine trade areas is provided every afternoon. Guest speakers from the shipyards periodically address the class. The curriculum includes generic skills and knowledges such as

material identification, ship layout, safety, use of common hand tools, shop math, and blueprint reading. It also presents basic unique skills and knowledges that are associated with painting, pipefitting, shipfitting, welding, sandblasting, fiberglass repair, electrician and mechanical tasks.

Hiring and Retention of Graduates

At the time of the survey, there had been 14 graduating classes. Over 90% of the graduates had been placed in shipyards, and about 65% were still working in shipyards. The employers reported that graduates have both desirable attitudes concerning work and are competent helpers.

THE SEATTLE AREA MULTI SHIPYARD COOPERATIVE APPRENTICESHIP TRAINING PROGRAM

Objectives

In contrast to the program in Norfolk, the Seattle area Multishipyard Cooperative Apprenticeship Training Program involves labor unions, the State of Washington, and ship repair and construction companies. The objectives of this joint effort is to ensure that: (1) programs produce qualified journeymen, (2) apprentices receive a well rounded technical exposure with as much additional training as is feasible, and (3) apprenticeships be completed if at all possible.

Geographic Description

Seattle has a population of approximately one-half million, with a population base of over one-million including surrounding areas. Like Norfolk, it is a center for international shipping and is fifth in containerized cargo tonnage. There are three major shipyards and over one-half dozen smaller yards in the area.

Program History

During the World War II, the government passed the Federal Apprenticeship Act. Shortly thereafter, the State of Washington passed its own Apprenticeship and Training Act, which closely paralleled the national act. This act established an Apprenticeship and Training Council under the State Department of Labor and Industries. This council is a relatively high level state body with members representing employers, employees, the public, and the State Vocational and Employment Security. The council approves and registers apprenticeship programs and training agreements. There are 11 craft unions involved in shipbuilding and repair in the Seattle area. Only four Boilermakers, Carpenters, Marine Electricians and Machinists have an apprenticeship program. In our study, we looked at two of these programs in greater detail. These were the Boilermakers and the Marine Electricians.

Legal Basis

Both programs are governed by the following agreements and regulations: the Masters Agreement between local shipbuilding and ship repair yards and the union, the State of Washington rules and regulations regarding apprenticeships, and the state-approved "Standards for Apprenticeship", which is agreement between union and management for a Joint Apprenticeship and Training Committee (JATC) to run the program. The Boilermaker program, which was initiated in 1947 and amended in 1982, legally indentures all Boilermaker apprentices to the, JATC for 6,000 hours over three years. The Marine Electricians program, was approved in 1982, and apprentices are indentured to the Seattle Electrical Workers Apprenticeship Committee for 6,000 hours.

Funding

Funding for the two apprentice programs is similar, but we were able to obtain detailed information on only the Boilermakers program. Employers are the primary

funding source, and their obligations are defined in the Master Agreement between the shipbuilding/ship repair firms and the unions. For the Boilermaker program, employers contribute $.03 per hour worked by employees covered under the agreement. These funds go into a trust account, whose sole purpose is to provide apprenticeship training materials and other training program support. The trust fund also receives a small contribution from a local vocational-technical institute that teaches courses at the Boilermaker School. This institute reimburses the Trust Fund for a portion of the tuition that is identified for school rental facility expense. Apprentices are paid on a graduating scale starting at 70% of the journeyman rate during the first 1,000 hours of the program and increasing to 95% of the journeyman rate during the last 1,000 hours.

Staff and Facilities

Both programs utilize instructors from the vocational institute for classroom work. Facilities for the Boilermaker program include the work site, the Boilermaker school that is attached to the local union headquarters, and the local vocational-technical institute. The Marine Electrical program also uses North Seattle Community College for formal classroom instruction.

Trainee Input

Applicants for both apprentice programs are at least 18 years old, high school graduates and they must pass an aptitude test. They are interviewed and ranked by the Joint Apprenticeship and Training. Committee. Employers/. are then offered names according to the applicants' rank. Employers may however, select someone on their own.

Curriculum

The curricula for both courses include 6,000 hours of job experience plus school requirements. THe job experience is broken down by activity and hours per activity. For example, a Boilermaker receives 150 hours of work in rigging. The school requirements are defined in term of courses and hours of instruction. The Boilermaker "apprentices must complete six 11 week courses (396 hours) plus 88 hours of welding, while the Marine Electrician apprentice must attend three hour classes, two nights per week (258 hours) for each of the first two years, and a three semester course during the final year.

Hiring and Retention

Hiring and retention data were available for only the Boilermaker program because the Marine Electrician program was only in its third year. In the five years of 1980 through 1984, 42 apprentices graduated from this program. The number per year fluctuated considerable, with 13 graduates in 1981 and only 4 in 1984. Retention of graduates was quite low because a sluggish level of shipyard activity coupled with a strong union seniority system. The graduate of the apprentice program becomes low person on the seniority list for journeymen and is the first in line for a lay off.

IDENTIFICATION OF OTHER GEOGRAPHIC AREAS

The scope of this project did not permit a detailed analysis of who might need what type of program and where. The analysis that was performed suggests that on a numbers basis, cooperative training might be appropriate in other areas. For example, relative to other centers of shipbuilding and repair activity, neither the Norfolk nor the Seattle area has the highest concentration of shipyards or the highest

import/export tonnage. The project leads to the conclusion that cooperative training programs may be of value in other areas, but only those in the local shipyards can assess their needs.

GUIDELINES FOR DEVELOPING AND IMPLEMENTING NEW PROJECTS

The guidelines presented in the project report are in the format of a sequence of questions. In answering these questions one will construct a roadmap for developing and implementing a program. Time does not permit going through each question in detail.

The first question, however, is, "Who should initiate action?" This question is important because typically there is no single person who would have this task as part of any job description. Basically, if you perceive the need and have the resources, the energy, and the contacts to make it happen, the answer may be you.

The development process requires detailed analyses of training needs in your area, of state and federal programs and resources, of union agreements, of local technical training institutions, of relevant state and federal laws. Many questions that are relevant to these analyses are presented in the project report. The development process also requires extensive coordination between some or all of the various entities mentioned above. Because each program may meet unique needs in a unique way, there is no single set of guidelines. The programs studied in this project, however, demonstrate that a cooperative training program can be a viable alternative in meeting your needs.

NORTHERN EUROPEAN CRAFT TRAINING
A Trip Report

Paul William Vickers
University of Michigan

The Education Panel of the Ship Production Committee is charged with conducting research on training methods and techniques and developing new training methods. As part of this effort, the panel funded a project to provide the means for on-site inspection and evaluation of craft training programs in Europe. In June of 1985, a four-person project team traveled to Northern Europe to meet with shipbuilding trainers and educators. This paper presents highlights of that trip. Discussed here are apprentice training programs of The United Kingdom and the Federal Republic of Germany, and adult training in Scandinavia.

Overview

A four-person team spent two weeks in Europe visiting training centers in England, Sweden, Denmark, and West Germany. The team consisted of James Wallace, Director of Training and Development at Newport News Shipbuilding; Steven Sullivan, Manager of Human Resources at Bethlehem Steel, Sparrows Point; and Howard Bunch and Paul Vickers of the University of Michigan. The project team visited three training centers in England run by British

Shipbuilders (Training, Education Safety) Ltd; two Scandinavian shipyards (Kockums in Sweden and Burmeister & Wain Skipswerft in Denmark); and two shipyards in West Germany (Blohm + Voss AG and Howaldtswerke-Deutsche Werft --Kiel). One engineering organization, Borsig AG, in West Germany was also visited. Table 1 lists the sites visited. Throughout the trip, first-class trainers, educators, and managers were encountered. They patiently answered many questions, and they answered in English. The personnel included shipyard presidents, directors, managers, and trainers, as well as local education officials. The interest of shipyard presidents and directors indicates the importance training has in European countries.

TABLE 1

Organizations Visited by Project Team

United Kingdom	British Shipbuilders (TES)	
	-----Hebburn Training Centre	Newcastle
	------Baqrrow Training Centre	Barrow
	-----Birkenhead Centre	Birkenhead
Denmark	Burmeister & Wain	Copenhagen
Sweden	Kockums AB	Malmo
Federal Republic of Germany	Borsig AG	West Berlin
	Blohm + Voss AG	Hamburg
	Howaldtswerke-Deutsche Werft AG	Kiel

Apprentice Training

The crafts of Europe have been regulated since the Middle Ages. Under the guild system, apprentice training evolved as a method of transferring the knowledge and skills of the older master craftsmen to their student apprentices. Upon completion of the apprenticeship, the student was indentured to the master for several years. The modern age has seen the dissolution of the guilds and the end of indentured apprenticeship, but the apprentice form of structured vocational training continues to be a vital part of the European heritage. Therefore, it is not surprising to discover thriving apprentice programs in Britain and Germany. On the other hand, apprenticeships have been deemphasized in Denmark and eliminated in Sweden. In the following sections, the situation in the four countries visited is briefly described.

British Apprentice Training. In the United Kingdom, an apprenticeship is an in-company, basic training period of four to five years. The length of the apprenticeship is determined by national negotiations between the union and employer associations. A shipbuilding apprenticeship is a four-year training program with one year off-the-job training followed by a three-year on-the-job planned work experience. The responsibility for apprentice training is shared by the sponsoring shipyard and the staff of the training center-who are employees of British Shipbuilders (Training, Education & Safety) Ltd. (BSTES).

BSTES is a non-profit, independent organization responsible for all facets of training and education in the British shipbuilding industry.

The foundation for apprentice training, as well as craft retraining, is the modular training system. The modular training system is a flexible yet well-defined, training scheme designed to ensure that skills are learned and demonstrated by the trainee to a standard skill level. The modular training system consists of modules and elements. A module is the set of skills and standards of workmanship required to work effectively in a given area of the shipyard. To complete the apprenticeship and receive a skilled worker certificate, an apprentice must complete three on-the-job modules. A module cannot be completed without a foundation--a set of skills to build on. The basic skills for various modules are developed at the training center during the first, off-the-job training year. Basic skills needed to successfully complete each module have been meticulously identified, defined, and assigned to elements as element levels.

The key to the system is the use of the standards of workmanship as the determining factor in completing an element-or module. The defined standard of workmanship must be met in order for the trainee to receive a certificate which documents the given training.

BSTES has made significant progress in instituting the modular training system and in providing realistic work situations at the training centers.

Table 2 lists crafts and skills for which modules and elements have been developed.

The modular training system is beneficial to shipyard management. The modular training system allows shipbuilding management to specify the skills of their apprentices precisely by specifying the elements and element levels taught during the basic training year. A shipyard can use this system to develop workers with diverse skills in any work area by assigning to that area apprentices and skilled workers who have completed different element levels and modules. The modules and elements can be mixed and matched to meet current or anticipated shop or ship needs. An added benefit of the modular training system is that the same elements and modules are used to retrain experienced workers--imparting new skills or improving old ones--which improves the quality of the work force and can, in fact, lead to a more flexible approach to work assignments. Also, through comprehensive record keeping, the skills and training of all employees are documented, aiding supervisor selection and work assignments.

<u>German Apprentice Training.</u> The German form of apprenticeship-the dual system-is a regulated, in-company, three year, basic training period. Apprenticeships are regulated by national laws concerning worker classification and are administered by the company and the local chamber of commerce. There are roughly 450 occupations or worker classifications,

TABLE 2

British Shipbuilders (TES) Crafts and Skills

TECHNICAL & DESIGN	COMPUTER & ELECTRONICS	FABRICATION , PIPE & WELDING	ENGINEERING	CLERICAL
Computer-Aided-Design	Network Installation	Ox-Gas Cutting	Shaping	Keyboard
Design Principles	Electronic Office	Welding to International Standard	Milling	Typing
Engineering Drawing	Computer Hardware	Plating	Center Lathe	Telephone
Freehand Sketching	Bureau Accounts	Sheetmetal	Painting	Filing
Geometric Drawing	Robotics	Heat Line Bending	Woodwork	Shorthand
Hull Definition	Basic Electronics	Heat Treatment	Fitting	Accounts
Hull Structure	Microcomputer Repairs	Drilling	Grinding	Writing
Layouts & Ergonomics	Word Processing	Tack Welding		
Piping Systems		Burning		
Plan Reading		Caulking		
Structural Steelwork		Shipwrighting		
		Plan Reading		
		Marking Off		

including the shipbuilding trades shown in Table 3. For each worker classification, the federal government sets general training plans and guidelines for apprentice examination. Upon completion of the apprenticeship, the trainee is tested by the local chamber of commerce to determine if the apprentice has reached a level of craftsmanship suitable to be awarded the title of facharbeiter, or skilled worker. Because of the national regulations and local testing, the German apprentice program is geared toward producing individuals who can pass that exam.

Similar to the British system, the first year is conducted off-the-job in a company-run training center. The apprentice receives training ranging from basic hand tool skills to operation of sophisticated, state-of-the-art machinery. All apprentices in a given occupation are required by law to receive similar training--regardless of the companies' needs, facilities, or personnel. Small companies that cannot afford the cost of the training center or the cost of special training equipment contract with German shipyards to provide training for their apprentices.

TABLE 3

Shipbuilding Apprenticeships in West Germany

Boilermaker/Smith	Joiner	Social Insurance
Boring Machine Operator	Fitter	Shipwright
Carpenter	Material Tester	Technical Draftsmen I
Commercial Employee	Milling Machinist	Technical Draftsman II
Data Processing	Office Worker	Turner
Electrician	Packer	Welder
Engine Fitter	Pipefitter	Woodworker

A key to the German system is the meister or master craftsman responsible for apprentice training. The meister is first and foremost a certified skilled worker-a facharbeiter. Second, the meister has completed a course of study to prepare for his role as an apprentice instructor. This course includes pedagogical training as well as course work in business and social sciences. Third, the meister has successfully completed a licensing examination.

The meister is charged with teaching the apprentices the skills necessary to succeed in a given occupation--or at least pass the facharbeiter examination. The success, or failure, of the meister may be measured by his students' success rate in the facharbeiter examination. The apprentice contract guarantees the student the instruction needed to pass that examination. Failure to pass results in new training and testing for the apprentice and a review of the meisters' credentials by the local chamber of commerce. But, this is a rare event. The success rate for shipbuilding apprentices is very high.

Another key to the success of the German system is the close ties to the public school system. The instruction, particularly for the non-university-bound students, has a definite and intentional industrial bias to prepare students for successful apprentice experiences.

Thus, through classification of skills, meister training, and pre-apprentice vocational training, the German dual system supplies its economy with skilled, highly productive workers.

Similarities Between British and German Apprenticeships.- Four points distinguish German and British apprentices: definition, training centers, instructors, and age. First, both countries have defined the skills needed to qualify as a skilled worker to a degree not normally found in the United States. Through elements and modules in the U.K. or by classification in Germany, the qualifications of a skilled worker are defined and certified. This implies a significant investment in training organization. Second, mandatory off-the-job training has led to the development of training centers--stocked with machinery and workspaces, including state-of-the-art machines. This means a significant investment in facilities and continuing improvements. Third, the importance of the instructors in British and German training centers is unique. In the U.K., instructors are typically older men with a great deal of experience who, in the twilight of their careers, transfer their knowledge to the younger tradesmen. In Germany, the meister is a certified craftsmen, businessman, and trainer. The meister holds an esteemed position in German society. The people involved in training apprentices adds a dimension to vocational training worth exploring further. Fourth, and last, is the age of the apprentice. That factor clearly

differentiates European apprenticeships from U.S. apprenticeships. Typically, a European will enter an apprenticeship at age sixteen. In the U.K., the person can be as young as fifteen and no older than seventeen. A U.S. shipyard could not employ a person of that age. Nor does the typical U.S. sixteen year old make a career decision at that age. The high proportion of students who enter college in the U.S. delays that decision for several years. Therefore, European apprenticeships are very youth oriented and apprentice programs are significantly influenced by the age of their charges.

Scandinavian Training

Denmark and Sweden emphasize adult training and retraining to a far greater extent than do Germany and Great Britain. Apprentice programs exist in Denmark but not in Sweden. Therefore, the resources of the shipyard training departments are directed toward an older and, in some cases, skilled work force.

Training in Denmark. Danish apprentice programs are jointly managed by labor unions and management. Following a one month training period in the shipyard training school, the apprentice alternates between periods in a state run school and on-the-job experiences. Shop skills are taught at the training school. On-the-job experiences are determined by the apprentice's supervisor

and are determined, in part, by the workload. After four years, the apprentice must pass a final examination to earn the title of skilled worker.

Of much greater importance to the Danish shipbuilding training staff is the development of the current work force. Danish shipbuilding employs significant numbers of unskilled workers who require training. Twenty percent of the Burmeister & Wain Skipswerft's work force is unskilled. The Danish government financially supports the training of unskilled workers in the shipyard training schools. After four years of experience and training, the unskilled worker can become a skilled worker. Therefore, the shipyard must ensure that these employees receive the necessary training to earn that title.

In addition to the shipyard training staff, outside agencies, such as the Danish Welding Institute , provide training in new skills, retraining of old skills, and testing of skills for the shipyards. Reliance on outside firms decreases the need for significant investment in training facilities and trainers.

Training in Sweden. The Swedish shipbuilding industry does not have a formal apprentice program. A small number of young people are hired from vocational schools at age sixteen. They must complete a vigorous program including nine months of basic skill training in welding, plating, and pipe work. Upon completion, they are given further on-the-job training but do not earn a title such as skilled worker.

The world-wide decline in shipbuilding orders has had a significant effect on the number of new hires and, thus, on the training program emphasis. Swedish shipbuilding has been in a recession. Shipyards have been closing. Those that have stayed open have been forced to cut back on the number of employees and change their product line. Thus, the training programs have changed to reflect the need for skills in demand as determined by the order book. For example, welders and platers are being retrained to be joiners and plumbers to build outfit intensive passenger ships instead of steel-work-intensive tankers. The training schools are smaller and oriented toward an older, experienced worker.

Scandinavian shipyards are oriented toward training older and, in some cases, skilled workers, in comparison to the shipyards of Great Britain and Germany. The Scandinavian shipyards have not invested as heavily in training centers or programs. The training schools which are employed are not directed toward training shipbuilders. The training staffs are smaller and are not necessarily licensed as vocational trainers. Yet the Scandinavians do consider education and training to be vitally important to their continued success.

Conclusions

The European shipyards stress the importance of developing and maintaining a highly skilled work force. Through apprentice training in the

United Kingdom and Germany and the adult training programs in Denmark and Sweden, European shipbuilders learn the skills needed to produce ships at a competitive price. The Europeans have developed new techniques and modified traditional apprenticeships to produce high quality empoyees. Especially important topics for future consideration are the modular training program in the United Kingdom; the use of licensed meisters as instructors, as practiced in the Federal Republic of Germany; and the use of standard qualifications and examinations for earning the title of skilled worker.

The modular training system allows British Shipbuilders to provide flexible training alternatives to meet the demands of production. Through on-the-job modules and training elements, experienced workers and apprentices can be given training in different skill areas to the needed skill level. This allows production managers to specifically determine the training needs of their workers.

In the Federal Republic of Germany, the meister is a licensed apprentice instructor as well as a skilled worker. The meister must demonstrate a level of competence in his craft and instructional competence not normally required in the United States. The meister is internationally recognized as a key component of the German training system.

The use of standard skill levels , qualification examinations, and certification provides solid documentation of worker skills and training. Documentation and certification allows management to better determine the best

employee for a given job or supervisory position. Standards as well as documentation requires a well-defined training system with training centers, trainers, and training administrators. This means a significant investment of money, men, and facilities. But, as Herr Berg of Blohm + Voss Shipyards says, "I am not telling you any secrets, training is expensive. The only thing which can be more expensive for a company is: Do not train."

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THE CERTIFICATE IN MANUFACTURING ENGINEERING - SHIP PRODUCTION: A NEW PROGRAM FOR SHIPYARD EMPLOYEE SELF-INSTRUCTION

BY

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ABSTRACT

The Manufacturing Engineering Certification Institute (MECI) of the Society of Manufacturing Engineers (SME), offers a peer recognition program for individuals involved within the many facets of manufacturing engineering and technology related career areas. The MECI certification program was developed in 1972 to provide manufacturing personnel with the means to document specific areas of expertise, to encourage continuing education, and to foster professional development.

Currently there are over 11,500 actively certified individuals in the MECI program of which about 1,000 are added annually.

In 1986, a new certification specialty in Ship Production will be added to those currently available to an individual applying for recognition as a Certified Manufacturing Engineer. This new area, developed under the direction of Professor Howard Bunch,. of the University of Michigan Transportation Research Institute, and MECI, will be offered to all qualified applicants beginning with the December, 1986 examination cycle. The purpose of this session is to introduce you to the new ship production speciality within the SME/MECI certification program, and to answer any questions you may have.

MECI Ship Production Certification

In 1372, the Manufacturing Engineering Certification Institute (MECI) was organized to provide manufacturing personnel with a means to document specific areas of expertise, to encourage continuing education, and to foster professional development.

Today, the Institute manages the Certification programs of the Society of Manufacturing Engineers (SME), and it's associations, the Association for Finishing Processes (AFP/SME), the Computer and Automated Systems Association (CASA/SME), Robotics International (RI/SME), and the Machine Vision Association (MVA/SME).

The institute also assists certification candidates by offering formal refresher courses in engineering fundamentals and provides various study materials related to the examinations. MECI also establishes examination sites, administers and grades the certification exams, and grants the appropriate certification title. In addition to initial certification, MECI provides a means for continued professional growth through periodic recertification. Thus, by qualifying for MECI certification, candidates can measure, document and are encouraged to update their technical knowledge.

During.the past 13 years, over 20,000 people have applied to become certified by MECI. In calendar year 1384 alone, 1,662 people wrote the examinations leading to MECI certification. These figures are representative of the last few years which shows a steadily increasing interest in the MECI program.

Since 1972, MECI certification has seen many changes. Some of these include:

We have gone from one level of certification to two, the Certified Manufacturing Engineer and the Certified Manufacturing Technologist. Now we can offer recognition to a person with as little as two years experience and/or education, as well as to the individual with a life time of knowledge.

We now offer recognition in four technologist areas and over 17 engineering specialty areas. Technologist specialty areas include finishing, robotics, and computer systems as well as the standard metal working SME area. Our engineering level has also been expanded to include robotics, computer integrated manufacturing and finishing, as well as manufacturing management, general manufacturing, and tool engineering.

In the first few years of the examinations, under 100 applicants per year completed the exams at a few selected sites. Today, over 1,600 applicants per year, sign up for the examinations, which are currently offered at over 150 examination sites, twice a year.

Beginning in 1984, and continuing today, there is an increasing emphasis upon the educational experience that MECI can offer to the employer as well as to the employee. We are now working with various companies, using MECI certification to some degree, within their in-house continuing education and recognition programs.

Today, we are pleased to announce that the newest SME certification specialty in ship production, will now be included as an area of

certification within the SME/MECI program. The new ship production specialty, will only be available at the certified manufacturing engineer level. This means that an individual must have a minimum of 10 years education and/or experience in manufacturing engineering, technology or related position. In addition to the education/experience, the applicant must also successfully complete two certification examinations. The first exam will be engineering fundamentals, covering the broad topics of engineering to include: mathematics, physics, engineering drawing,.. statics and strengths of materials, metallurgy, etc. The second, or specialty exam will deal specifically with ship production. The content of this exam will be decided by the examination development committee. In addition to the examination, a study guide will also be developed by the examination authors. The purpose of the study guide will be to assist the applicants in preparing for the MECI ship production certification exam.

The target date for offering this new examination is December of 1986. In order to accomplish this, the study guide must be completed by June of 1386 and the exam shortly thereafter. Applicants may then schedule the ship production exam during any one of two testing cycles, the first Saturday in December and the second Saturday in May. Applications must be sent to MECI approximately GO days previous to the examination date. This will allow us to arrange an examination site within a few miles of the applicants home. Examination sites are arranged through the network of SME chapters, located throughout the world, almost assuring applicants that the exam will be taken within 50 miles of their home. This large

and growing network can only be offered by MECI and SME.

Once-initial ship production certification is granted by MECI/SME, certification must be maintained through a process called recertification. Recertification addresses the question of continuing education and life long learning. Every three years the certified individual must submit a minimum of 36 clock hours of professional development activities. Recertification encourages the certified individual to become involved in an educational program that will help to maintain their expertise; If this is not accomplished, their certification is dropped and can only be renewed through reapplication and reexamination. The recertification program assists the certified individual in maintaining their level of proficiency and provides evidence of other educational activities. A print out, or registry, is available to all MECI certified people, which display the [redacted] Continuing Education they have submitted for recertification.

This new ship production program will be administered in the identical way that al.1 other MECI specilaty certifications are. Ship production will be included as part of our regular SME specialty areas. Applicants will fill out the appropriate application and submit it, with the appropriate fee, to MECI and be placed in an examination site close to their home. Upon successful examination passage, the newly certified individual will be recognized by SME as a certified manufacturing eng'ineer in ship production.

Each certified individual will be issued an ID card and a wall certificate which notes their MECI recognition. All people will have a

certification number unique to the ship production area, which will allow us to keep track of the results of this new program.

We, at SME and MECI, are looking forward to offering the new specialty in ship production. Not only do we offer a fine program to you, those individuals involved in ship manufacturing, but this also gives us a chance to broaden and expand our scope to include a major manufacturing area. We, at SME, are confident that the new venture between SME and the ship producers will be a very fruitful program for all involved.

PANEL SP-10

FLEXIBLE MANUFACTURING

James B. Acton
Todd Pacific Shipyards

Chairman

A COMPUTERIZED ROBOT SELECTION SYSTEM

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ABSTRACT

Attributes which should be considered when selecting a specific robot model are identified. Some of the attributes are specifications necessary to determine a set of feasible robots which are capable of performing a particular task. Other attributes pertain to the selection of a single robot model from the set of feasible robots. However, some attributes fall into both categories.

The robot selection model was implemented on an IBM PC using the R:BASE (a relational database management system by Microrim, Inc.) coupled with a BASIC program. The database consists of forty-nine robot models representing twenty vendors. The software consists of three phases. In the first phase, a feasible set of robot models is determined. The user is presented with a list of forty-five attributes and permitted to enter specifications for any or all attributes.

In the second phase, the user is presented with a list of twenty-nine attributes which are possible selection criteria. The user is then allowed to specify (up to a maximum of fifteen) attributes judged most important. The final phase of the software uses a BASIC program to interrogate the user regarding preferences and priorities with respect to the attributes being used as selection criteria. The information obtained from the interrogation is entered into the decision model and the most preferred robot model in the feasible set is determined.

A COMPUTERIZED ROBOT SELECTION SYSTEM

A. INTRODUCTION

The purpose of this paper is to describe an aid for using software which has been designed for the selection of the preferred robot model from a set of commercially available robots. This software was developed with funding from SHAME SP-10, who is responsible for its distribution.

The software includes an implementation of the relational database management system, R:BASE™, and the use of a BASIC program called JONES. Only the features of R:BASE™ which are necessary for this particular application are discussed. The hardware required is an IBM PC with 256 kilobytes of memory and 2 disk drives. Printer capability is optional. To use this software the user must have some basic knowledge of the operation of the hardware.

The robot model selection software is implemented in three phases. The first phase allows the user to define his requirements or specifications for any or all appropriate attributes. In the second phase, the user selects the set of attributes which will be used as decision criteria to determine the most preferred robot in the feasible set. The third phase uses the BASIC program JONES and interrogates the user regarding his preferences for the attributes being used as decision criteria. The program then presents the robots in the feasible set, ranked from most preferred to least preferred.

The complete software package consists of the following diskettes: R:BASE™ Diskette I, R:BASE™ Diskette II, Database, and JONES. Tables 1-3 give a descriptive analysis of the database.

To begin, place R:BASE™ Diskette I in Drive A and load the operating system from ths diskette. Place the Database diskette in Drive B. When the operating system has been loaded, then R:BASE™ is entered by typing RBASE and pressing [RETURN]. The screen should appear as shown in Screen 1 below.

```
****************************************************************
*  Current date is Tue  1-01-1980                              *
*  Enter new date:  5-25-84                                    *
*  Current time is  0:00:23.17                                 *
*  Enter new time:  8:00                                       *
*                                                              *
*                                                              *
*  The IBM Personal Computer DOS                               *
*  Version 2.10 (C) Copyright IBM Corp. 1981, 1982, 1983       *
*                                                              *
*  A>rbase                                                     *
****************************************************************
```

Screen 1

Then, press [RETURN]. Screen 2 should then appear.

Follow the instructions on Screen 2: remove the R:BASE™ Diskette I from Drive A and replace it with R:BASE™ Diskette II.

The first step in R:BASE™ is to open the database named ROBOTS, which is stored on the Database diskette in Drive B. The command is OPEN B:ROBOTS. B:ROBOTS. Then, hit [RETURN]. The screen should appear as shown in Screen 3.

```
*************************************************************
* Begin R:base 4000 Version 1.01 MSDOS Serial # ######      *
* For the IBM Personal Computer                             *
* Copyright 1983 by Microrim, Inc.                          *
*                                                           *
* For assistance type "HELP", for Prompt mode type "PKOMPT" *
* R>open b:robots                                           *
* Database exists                                           *
*R>                                                         *
*************************************************************
```

Screen 3

Table 1. Summary of Numeric Attribute Values in the Robot Database

Attribute	Minimum	Average	Maximum
Resolution (in.)	0.0008	0.045	0.300
Accuracy (in.)	0.0004	0.037	0.400
Repeatability (in.)	0.0004	0.030	0.300
Wrist Roll (degrees)	180	330	900
Wrist Yaw (degrees)	90	221	370
Wrist Pitch (degrees)	90	197	270
Numoer of Axes	4	5	12
Maximum Reach (in.)	16	66	131
Maximum Velocity (in./sec.)	4	56	315
Load Capaciy (lbs.)	2	152	2000
Steps	99	2169	38000
Memory Size (kb)	1	44	256
Weight of Robot (lbs.)	35	2128	12000
Floor Space (ft.^{2})	1	19	110
Min. Environ. Temp. (F$^{\circ}$)	22	38	50
Flax. Environ. Temp. (F$^{\circ}$)	104	116	140
Cost (initial)	$ 5500	$69936	$225000
Number Installed	10	403	2000
Delivery Time (days)	30	106	270
Length of Warranty (days)	90	347	365
Service Cost ($/day)	350	486	600

Table 2. Tally of Features Available on Robots in the Database.

	Available	Unavailable	Information Missing
Programmable Velocity	40	9	0
Synchronized with Surrounding Equipment	47	1	1
Diagnostic Software	42	6	1
Service Contract	39	10	0
Mass Storage System	38	10	1
Additional Memory	13	0	36

Table 3. Summary of Actuator Types on Robots in the Database.

Actuator Type	Number	Max. Load Capacity (lbs.)	Min. Cost	Max. Cost	Minimum Repeatability (in.)	Maximum Velocity (in./sec.)
Electric	19	150	$28,500	$140,000	0.0010	315
Hydraulic	19	2000	$28,000	$225,000	0.0050	79
Pneumatic	11	33	$ 5,500	$ 45,000	0.0004	24

```
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMR:BASE SERIES 4000MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:                   *****************                                         :
:              **************************                                     :
:           ********************************                                  :
:         ***********************************                                 :
:        *************************************                                :
:      ****************     ******************                                :
:     ***************         ****************                                :
:    ***************         ****************                                 :
:    **************      *******************                                  :
:   ***************  *********************                                    :
:   ***************  ********************                                     :
:  ****************  *********************                                    :
:  ****************  **********************                                   :
:  ****************  ***********************        (C) Copyright 1983        :
:  ****************  ************************         by MICRORIM, Inc.       :
:  ****************  *************************           Bellevue, Wa.        :
:  ****************  **************************          (206) 453-6017       :
:  ****************  ***************************                              :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMNext disk pleaseMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:  Please insert the second diskette and press any key to continue.           :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

Screen 2

B. ROBOT MODEL SELECTION

1. Determine the Feasible Set

To begin the selection process, type PROM FEAS, and then press [RETURN]. Then, Screen 4 should appear with the cursor making the appropriate space for the entry. As explained in Screen 4, the next screen to appear (Screen 5) will show a list of attributes and their two digit codes. To get the list of attributes and their code, enter CODE on Screen 4. Then, Screen 5 should appear. If a code number is preceded by an asterisk (*), then some data regarding what is available for that attribute in the current feasible set will be displayed prior to the user being required to enter his specification(s). If these attribute entries are text (string), then a tally of what possibilities are in the current feasible set is shown. Screen 6 is an example of what would be displayed if 28 (for actuator type) were entered on Screen 5.

```
***********************************************************
*    actuat                       Number of Occurrences   *
*                                                         *
*    electric a.c.                          2             *
*    electric d.c. servo                   16             *
*    electric d.c. steppe                   1             *
*    hydraulic                             19             *
*    pneumatic                             10             *
*                                                         *
* Press any key to continue                               *
*********************************************************
```

Screen 2

If the attribute entries are numeric values, then the minimum and/or maximum (depending on the specific attribute) attribute value for the current feasible set will be displayed. Screen 7 is an example of what would be displayed if 40 (for cost) was entered on Screen 5.

```
*****************************************************
*  cost    Minimum =   28500                        *
*  cost    Maximum =  140000                        *
*                                                   *
*  Press any key to continue                        *
*****************************************************
```

Screen 7

After the information regarding attribute values in the current feasible set have been displayed, the next screen will allow the user to input his specification for that attribute. For example, Screens 8 and 9 are the ones which would follow Screens 6 and 7, respectively. If the information displayed indicates to the user there are no models which will meet his requirement, he should press [Esc] and the [Q] (to quit) when the screen for entering values is presented. After the user specifies an attribute value, he is returned to the list of attributes and codes to continue the inputting of attribute specifications, one at a time.

The user does not have to specify attribute values for each attribute. Rather, he may specify values only for those judged important to him. he may also specify more than one value for those attributes which have several choices available. However, the specifications must be made one at a time. For example, assume the user wants a robot which is capable of performing welding and spray painting. He would enter code 10), enter WELD (see Table 4) on the screen that follows, and be returned to the list of attribute codes. Then he would enter code 10 again, enter SPR PNT (see Table 4) on the next screen and return to the list of codes. His current feasible set of robot models would contain only models which are capable of performing both tasks. The attributes which allow the user to enter more than

```
Push [ESC] when done with this data
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMPROMPTSMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
: You are now in the section that will allow you to specify certain features :
: or specificatios that a robot must have to be considered feasible for      :
: purchase.                                                                  :
:                                                                            :
: The next screen will show the attributes (and their respective codes) that :
: have been identified as possible selection criteria. You will be allowed to:
: enter specifications for any or all of the attributes. To be able to spe-  :
: cify an attribute value, type its code number where you see the cursor at  :
: the bottom of the list. If an attribute is marked with an * , you will be  :
: shown some information on what is available before you have to input       :
: your requirement. After you have input your requirement for an attribute,  :
: you will be returned to the list to select another. When you have speci-   :
: fied all the attributes you wish to, input 99 to move the program to the   :
: next section.                                                              :
:                                                                            :
: If you have questions, please refer to the User's Manual for a more        :
: thorough explanation.                                                      :
:                                                                            :
: When you are ready to review the list, type CODE:code                      :
:                                                                            :
: After CODE is typed correctly, press [Esc]; then [G].                      :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

Screen 4

```
Push [ESC] when done with this data
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMPROMPTSMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:   10 Applications              *26 No. of axes           *42 Reputation          :
:   11 Sensors                   *27 Coordinate system     *43 Load Capacity       :
:   12 End effectors             *28 Actuator type         *44 Max. velocity       :
:   13 Power requirement         *29 Motion control        *45 Warranty length     :
:   14 Operating cost            *30 Control system        *46 Service cost        :
:   15 Memory technology         *31 Reach                 *47 Min. envir. temp.   :
:   16 Oper. control inputs      *32 Resolution            *48 Max. envir. temp.   :
:   17 Std. input devices        *33 Accuracy              *49 Programmable vel.   :
:   18 Operation language        *34 Repeatability         *50 Synchronization     :
:   19 Control language          *35 Roll                  *51 Diag. software      :
:   20 Manuals supplied          *36 Pitch                 *52 Mass stor. system   :
:   21 Training courses          *37 Yaw                   *53 Service contract    :
:   22 Number installed          *38 Memory size           *54 Additional memory   :
:  *23 Floor space               *39 Steps                                         :
:  *24 Weight of robot           *40 Cost                  99 GO TO NEXT SECTION   :
:  *25 Training location         *41 Lead time                                     :
:                                                                                  :
:  To specify an attribute value, enter the number given beside it:                :
:                                                                                  :
:  When the number has been entered correctly, press [Esc]; then [G].              :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
```

Screen 5

```
Push [ESC] when done with this data
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMPROMPTSMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:                                                                            :
:                    ACTUATOR TYPE                                           :
:                                                                            :
:    Enter the type of actuator your robot must have from the                :
:    possibilities shown on the previos screen.                              :
:                                                                            :
:    ACTUATOR TYPE:                                                          :
:                                                                            :
:    When the type of actuator required has been entered correctly,          :
:    press [Esc]; then [G].                                                  :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

Screen 8

```
Push [ESC] when done with this data
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMPROMPTSMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:                                                                                :
:                      COST                                                      :
:                                                                                :
:  Enter your budget constaint or the maximum amount you are willing            :
:  to pay for the robot.                                                         :
:                                                                                :
:  COST LIMITATION:                                                              :
:                                                                                :
:  When the maximum amount you are willing to pay for a robot has               :
:  been entered correctly, press [Esc]; then [G].                                :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

Screen 9

one specification are: end effectors, sensors, applications, memory technology, operator control inputs, standard input devices, manuals supplied, and training courses.

Table 4 shows the attributes for which the user must enter a choice from a set, but receives no information from the software as to what is available. It should be noted that the list of choices is from the complete database set of robot models, and it is possible that there are no models in the current feasible set which contain that value.

When all the user's specification have been entered, a code of 99 is input to move' the software to the next section. This section will allow the user to specify which attributes he wishes to use as decision criteria.

2. Specify the Decision Criteria

After the number 99 is enterd on Screen 7, Screen 10 will appear. After LIST has been entered on Screen 10, Screen 11 will appear. The user then specifies the attributes to be used as selection criteria by entering the attribute codes one at a time. Note that the codes on Screen 7 are different from the codes on Screen 11.

The user is again reminded to limit the number of attributes selected to fifteen or less. There is no method in R:BASE™ to limit the number selected, but if it is greater than fifteen there will be a problem reading the data later in JONES.

3. Determine the Most Preferred Model

The program JONES first reads the data (from the previous use of R:BASE™). It then checks to see if any model(s) dominate, i.e., if

Table 4. Attribute Values Available.

Code	Attributes	*Possible Choices
10	Applications	die cast, forg, inv cast, MTLU, parts trans, spr pnt, sm pts asm, finish, plas mold, weld, mach, elect asm, inspec, pallet, other.
11	Sensors	tracking sensors, part detection, force feedback sensors, vision, priximity.
12	End effectors	welding torch, pickup gripper, custom, magnetic vacuum, gun mounts, hydraulic toggle, internal gripper.
15	Memory technology	cassette, cartridge, disc, wire memory, PROM, RAM EPROM, bubble, ROM, core.
16	Operator control inputs	teach pendant, CRT, editing terminal, CAD link PC programming.
17	Standard input devices	con closure, switch, floppy, key, tape, CAD, teletype, cassettes, pendant.
18	Operation language	modified NC, PASCAL, assembler, custom.
19	Control language	modified NC, assembler, machine, PASCAL, custom.
20	Manuals supplied	operations, maintenance, installation, programming, parts, elect draw.
12	Training courses	operations, maintenance, programming, application development.

```
Push [ESC] when done with this data
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMPROMPTSMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
: From the previous screens you have created a feasible set of robots     :
: from the database of commercially available robots. The next step is    :
: to determine which model from the feasible set is best suited for       :
: your present situation. Given on the next screen is the list of         :
: attributes which may be used as decision criteria. You are to choose    :
: the ones you wish to use. It is suggested that you try to limit         :
: the number of attributes chosen to between 8 and 15.                    :
:                                                                         :
: You will be asked to select the attributes one at a time. RBASE will    :
: return you to the list after each selection. Then you will select the   :
: next attribute. When you have selected all the attributes you wish to   :
: use enter 100 and the program will advance to the next stage.           :
:                                                                         :
: To begin this stage input LIST:                                         :
:                                                                         :
: When you have entered LIST correctly, press [Esc]; then [G].            :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

Screen 10

```
Push [ESC] when done with this data
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMPROMPTSMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
: 70 Operating cost          80 Number installed      90 Max. envir. temp.        :
: 71 Weight                  81 Number of axes        91 Max. velocity            :
: 72 Floor space             82 Reach                 92 Reputation               :
: 73 Resolution              83 Roll                  93 Programmable velocity    :
: 74 Accuracy                84 Pitch                 94 Synchronization          :
: 75 Repeatability           85 Yaw                   95 Diagnostic software      :
: 76 Cost                    86 Memory size           96 Mass storage system      :
: 77 Lead time               87 Steps                 97 Service contract         :
: 78 Service cost            88 Load capacity         98 Additional memory        :
: 79 Min. envir. temp.       89 Warranty length     100 GO TO THE NEXT SECTION    :
:                                                                                 :
: To specify an attribute as a selection criterion, enter the number given       .
: beside it. (Please note the attribute codes are different from the ones        :
: given on the previous list):100                                                 :
:                                                                                 :
: When the number has been entered correctly, press [Esc]; then [G].              :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

Screen 11

any model(s) has the best possible value for all attributes. If it finds such a model(s) the user is informed and execution terminates.

If no robot models dominate, then the user must define the functions ($v_j(x_{ij})$) which best describe his preferences for each attribute. See Screen 12. Some possible functions, their descriptions, and implications are provided in the User's Manual. If the user finds a curve that describes his preference for the particular attribute, then he enters the number (1-14) of the curve. If no curve adequately describes his preference for the attribute, a preference value function can be defined by the user. Examples are shown in Screen 13. In Screen 13, note that the program has read the attribute codes and knows whether a lower value for the attribute or a higher value for the attribute is more preferred.

```
*************************************************************************
*                                                                       *
* You will now be asked to pick a value function                        *
* curve for each attribute                                              *
* Please study the curves and their descriptions in the User's Manual   *
*                                                                       *
*                                                                       *
*                                                                       *
* For the attribute repeatability                                       *
* Do you want to use one of the standard curves or define your own?     *
* Enter the number of the curve which best describes your value         *
* function, or enter 0 to define your own curve? 2                      *
*                                                                       *
*                                                                       *
*                                                                       *
* For the attribute cost                                                *
* Do you want to use one of the standard curves or define your own?     *
* Enter the number of the curve which best describes your value         *
* function, or enter 0 to define your own curve? 0                      *
*                                                                       *
*************************************************************************
```

Screen 12

```
***********************************************************
* The attribute is cost                                      *
* If the minimum value is  28500                             *
* and is assigned a value of 1                               *
* and if the maximum value is 75000                          *
* and is assigned a value of 0                               *
* What value would have a scale value of .25? 40000          *
* What value would have a scale value of .5? 55000           *
* What value would have a scale value of .75? 67000          *
***********************************************************
```

Screen 13

It should be noted that for the attribute, reputation, the following arbitrary preference values have been assigned: excellent = 1, good = .67, fair = .33, poor=0, and untested = 0. For the other discrete attributes, the preference value for a specific model is 1 if the attribute is available on a particular robot model, and 0 if the attribute is not available or the information was not given by the robot vendor.

After preference value functions have been defined for each of the numeric (continuous) attributes, the user is asked to select a decison model. See Screen 14. Model 1 will require the user to first rank the n continuous attributes from 1 to n. See Screen 15. If the rank entered is not a value between 1 and n, or another attribute has already been assigned that rank, the user will receive an error message.

The next section of Decision Model 1 interrogates the user regarding trade-offs of attribute values. An example is shown in Screen lb. In this example, number of axes has been ranked higher than repeatability. The user is given a hypothetical robot model with the best value for repeatability (the lowest value) and the worst value for the number of axes (the lowest value). This robot model is to be compared

against another model with the worst value for repeatability (the highest value). The user must decide how many axes the second robot model would need in order for him to be indifferent between the two robot models. The process begins with the best value of the second-ranked attribute being traded off to gain a better value for the first-ranked attribute. It continues with this pairwise trade-off interrogation, until the nth-ranked attribute is traded off for an improvement in the (n-l)th-ranked attribute. The value entered must be between the minimum and maximum values for the attribute in question. If it is not, the user will receive an error message, the appropriate range will be displayed, and the user will be requested to re-enter the value.

After this pairwise comparison for the numeric attributes, Decision Model 1 then addresses the discrete attributes. Screen 17 presents an example. The user is informed that a model with the best

```
*************************************************************
* You must now consider the attribute dia. software         *
*                                                           *
* A model with the best value for all attributes            *
* is given a rating of 100.                                 *
* A model with the worst value for all attributes is        *
* given a rating of 0.                                      *
*                                                           *
* What would be the rating of a model with the best         *
* value for all attributes except dia.' software            *
* but with dia. software not available on that model        *
*                                                           *
* Enter the rating for the model with dia. software missing *
* ??                                                        *
*************************************************************
```

Screen 17

value for all attributes is given a rating of 100. A model with the worst value for all attributes is given a rating of 0. The user must decide what rating a robot model should be given which has the best

IF you feel Comfortable with your knowledge of robots and their associated attributes, you will be allowed to define the sealing constants through a decision model (Model 1) which will interrogate you regarding trade-offs of attribute values.

If your knowledge of robots is limited, or this is the first time you have selected a robot, a simpler model (Model 2) is available.

A description of each model is given in the User's Manual
Please enter the model you prefer ?

Screen 14

By this method of determining scaling constants you will be asked to 1) rank the attributes in order of least important to most important 2) given a fixed value of an attribute,input how much **you wou1d** be **willing** to give up in order to have more of another attribute

There are 3 attributes to rank. When an attribute name is given please input a value between 1 and 3 each rank should be different.

Enter the rank for no. of axes
Rank?

Screen 15

Given a robot model with a value of 28500 for cost
and a value of .06 for repeatability

If another model had a value of 75000 for cost
What approximate value would repeatability have to be for you to be
indifferent between the two models if all other attributes
were the same for both models

Enter the value here?

Screen 16

value for all attributes, except the attribute in question is not available. This is repeated for each discrete attribute which was chosen by the user as a selection criterion.

The final step in Decision Model 1 requires the user to enter the rating of importance of a robot model with the numeric attributes at their best, and the discrete attributes at their worst, i.e., when none of the discrete attributes are available. See Screen 18.

Decision Mode1 2 only requires that the user rate each attribute (numeric and discrete) on a scale of 1 to 10. A rating of 1 indicates the attribute is unimportant, and a rating of 10 indicates the attribute is very important. The ratings do not have to be unique. Screen 19 shows an example of the interrogation for Decision Model 2.

After the program JONES has interrogated the user to obtain the information necessary for the decision model being implemented, the results are displayed. Screen 20 shows the results for an example with a feasible set of 7 robot models being considered. The format of the results is a rank for each robot (according to most preferred to least preferred), the model name, the vendor name, and the preference value ($V_j(X)$,). The user is then given an option to re-run the program with different preference value functions and scaling constants to determine how sensitive the preference value is to these variations. That is, does a slightly different preference value curve result in a different robot model being the most preferred? When the user has run the program enough to feel satisfied with the preference value results to make a final selection, then he should enter NO as the last entry. After the screen returns an OK, the user may return to the command system (operating system) by simply typing SYSTEM.

What ratlng on a scale of 1 - l00) would a robot model have if none of the following attributes (features) were available, but all the other attributes were at their best.

die. software
service cont.

Enter the rating?

Screen 18

P, this method of determlning scaling constants you will only be asked to rate the importance of each attribute on a scale of 1 to 10 where 1 is unimportant and 10 is very important.

For the attribute repeatability what rating (1-10)
would you give it? 6

For the attribute cost what rating (1-10)
would you give it? 3

For the attribute load capacity what rating (1_10)
would you give it?

Screen 19

Rank	Model	Vendor	Preference Value
1	RR650	Reis Machines Inc.	.9531402
2	RR625	Reis Machines	.8282857
3	IRb 6/2	ASEA	.7564738
4	GMF A-1	GMF	.7452723
5	P-5	General Electric	.7236279
6	Maker 100	United States Robots	.6840468
7	GMF M1-A	GMF	.5900141
8	7535	IBM	.550063
9	Apprentice	Unimation	5.468621E-02

This concludes the program. Do you wish to run it with other value functions and scaling constants as a sensitivity check? Enter 'yes' to re-run; 'no' to terminate?

Screen 20

ISLANDS OF AUTOMATION IN SHIPBUILDING

By

Robert J. Bellonzi
Bath Iron Works

ABSTRACT

Many experts believe that automation techniques, applied independently of corresponding system improvements, will produce only limited results in productivity improvement. However, a number of opportunities are available in shipbuilding for substantial productivity improvement by implementing stand-alone automation technologies (sometimes called "islands of automation").

The challenge to increase the level of automation in shipbuilding can best be met by matching proven technologies. with those opportunities that justify automation. Proven automation technologies are readily available and government programs are in place to provide the shipbuilder with both financial and technical support. Effective implementation of automation technologies can be greatly enhanced by following a few basic points in project development and control.

Program results at Bath Iron Works have demonstrated that implementation of "islands of automation" can result in substantial productivity improvement.

ISLANDS OF AUTOMATION IN SHIPBUILDING

INTRODUCTION

A recent article written about u.S. shipbuilding productivityivity states that automation technology; applied independently of corresponding system improvements, such as group technology andand process lanes, will usually produce only limited results in productivity improvement.[1] While I generally agree with this conclusion, our own experience with production automation programs at Bath Iron Works (BIW)[2,3] clearly demonstrates that a number of excellent opportunities are available in shipbuilding for substantial productivity improvement by implementating stand-alone (i.e. system independent) automation technologies (which are referred to in this report as "islands of automation").

A major government commitment exists today for improving shipbuilding industry productivity, mainly through the development and implementation of automation technology and system innovations. This commitment is emphasized in a number of government sponsored publications which include the National Shipbuilding Research

Program (NSRP) Long Range Productivity Plan (Figure l), dated September, 1984, and the Naval Sea Systems Command (NAVSEA) Integrated Robotics Program Annual Report (Figure 2), dated December, 1984. With this commitment to improve shipbuilding productivity, the shipbuilding industry presently has an outstanding opportunity to obtain substantial government support, both technical and financial, for the implementation of "islands of automation" in ship construction.

THE CHALLENGE

A major challenge of the shipbuilding industry for improving productiuity is to increase the application of proven automation technologies for ship construction. In this regard, approximately 6,500 robots are presently at work in other U.S. industries, performing welding, painting, inspection, assembly, and machine loading operations,[4] yet I am not aware of a single robot actually performing work in shipyards today on a continuous production basis. Furthermore, of some twenty shipbuilding/weapons manufacturing robotics projects listed in the NRVSEA Integrated Robotics Program, only two are identified as being performed by shipyards.[5]

The U.S. shipbuilding industry itself recognizes and emphasizes the need to concentrate on implementation of proven technologies. For instance, the NSRP Long Range Productivity Improvement Plan states that "the immediate emphasis (of this Plan) must be the implementation of existing technologies that have already demonstrated their effectiveness in foreign applications or in other segments of industry within the country."[6] The

Department of Defense also emphasizes the implementation of proven technologies in the DoD statement of principles for the Manufacturing Technology Program, dated March 14, 1980, which states that "technical feasibility has been previously demonstrated before procurement-funded manufacturing technology projects are initiated." [7]

The challenge to increase the level of automation in shipbuilding can best be met by matching proven automation technologies with those operations that justify automation, and by effectively managing these automation programs to ensure obtaining the desired results. This report emphasizes how BIW is meeting this challenge in its own automation programs.

IDENTIFICATION OF AUTOMATION TECHNOLOGY OPPORTUNITY AREAS

The identification of appropriate operations for automation in shipbuilding can be simplified by adopting an informal evaluation procedure which has been very successful at BIW. BIW first identifies those manufacturing operations having high labor content and (generally) consisting of low technology processes. Typical of such operations in shipbuilding are those of manual layout, painting, cutting, burning, welding, material handling, etc. To ensure that the maximum number of candidate operations for automation are identified, this initial phase should be performed without consideration of available technologies. Applicable government funded reports can also be used effectively to augment the findings of self-assessment studies for identifying the candidate operations. One such report used extensively by BIW for this purpose is the Maritime Administration Technology Survey of Major U.S. Shipyards, dated July, 1978.[8] This survey rates the average level of technology of thirteen major U.S. shipyards (Table 1) for seventy-two distinct shipbuilding operations against a consistent set of internationally applied standards.

The final phase of this recommended evaluation process is to identify suitable automation technologies for each of the candidate operations, and to select the one technology that is considered to be most effective in improving productivity. In this matter, BIW has relied entirely on technical proposals from leading equipment manufacturers to identify and select sound automation systems (hardware and software).

The evaluation procedure described above resulted in the selection of a highly successful computer controlled sheetmetal fabrication system (Figure 3) to automatically produce sheetmetal parts for ventilation assemblies (Figure 4) at BIW. This same evaluation process also resulted in a recent BIW proposal to implement a robotics shapes fabrication system (Figure 5) for the automatic production of structural shapes (Figure 6). The selected robotics systern is projected to eliminate the low technology, labor intensive methods presently used for structural shapes fabrication, at the Bath shipyard (Figure 7).

KEY POINTS FOR PROGRAM SUCCESS

Effective implementation of automation technologies can be greatly enhanced by adhering to the following key points for program success :

- o Use <u>fully proven</u> technologies. This allows the shipbuilder to concentrate his efforts on application, rather than development, of automation technology, thereby increasing the chance of program success. The two BIW automation programs combine <u>proven</u> equipment technology and specialized computer software to provide effectively integrated systems. The success of the sheetmetal fabrication system has been demonstrated by reducing ventilation component fabrication labor by 54%. I am also confident that the proposed robotics shapes processing system will be equally successful at reducing fabrication labor.
- o Limit the financial risk of the program. With the generally high levels of capital investment associated with automation systems, financial risks to the individual shipyard can be substantial. These risks can be reduced to acceptable levels through cost sharing of such programs with the government under either the Maritime Administration Ship Producibility Research Program or the Navy Manufacturing Technology Program. A third program, the navy Industrial Modernization Incentive Program (IMIP), provides financial incentives to contractors for increasing the level of productivity related capital investment. Although this program does not provide for government cost sharing, it does reduce financial risk by allowing the contractor a larger share of resulting project savings.

- o Plan for future technology enhancements. If anticipated technical developments can be incorporated in the automation system at a later date, the original system should be designed with sufficient flexibility to readily add such enhancements. Typical enhancements might include the addition of computer aided design capability to a computer controlled machine, or the addition of automated material handling to an automatic fabrication operation. Regardless of the nature of these enhancements, initially providing for their incorporation at a later date will usually result in substantial increases in productivity, with minimum additional cost and effort. For instance, BIW is developing the Robotics Shapes Processing System software to readily accept a computer aided design and manufacturing capability (Figure 8) at a later date.
- o Develop the project schedule around measurable and attainable results-oriented milestones. This is the most critical item for program success because it provides the basic control for both schedule and cost performance, and is especially necessary for those projects where subcontractor progress payments are related to performance against discrete mile-stones. The subcontractor should participate directly in the project schedule development process at the outset to ensure the mutual agreement between the shipbuilder and subcontractor that all project milestone target dates are achievable, and that there are a sufficient number of interim reviews specified in the schedule to measure subcontractor progress. These points for effective project schedule development are reflected in the, BIW project (schedule for the robotics structural fabrication system (figure 9).

- The major milestone tasks are broken down into a number of discrete and easily measurable sub-tasks. Also, where necessary, the schedule includes interim design reviews.
- The first project schedule task is the development of the system functional specifications. These specifications must clearly identify all operating requirements of the automation system before beginning the development of subsequent project tasks. Preparation of functional specifications for this program was accomplished jointly with the subcontractor to ensure an effective fit between the resulting system and the shipyard operating requirements.
- The highly technical tasks such as equipment design, software development, and system integration and test are the responsibility of the subcontractor, with BIW's efforts concentrated on program management, systems installation, and training. BIW considers that technology development should remain with those industries that are best equipped with the necessary technical expertise and resources for such work.

- o Establish a permanent organization at the outset of the program. It is vital that this organization be structured to ensure top management support, and include permanently assigned production and technical personnel throughout the program. The Robotics Shapes Fabrication Project Organization (Figure 10) meets these requirements by organizing under the Senior Vice President of Operations and by establishing a project implementation team with permanently assigned people from Systems (CAD/CAM), Industrial Engineering, Production Planning (Mold Loft), Plant Engineering, and Production.

Summary

Implementation of "islands of automation" in shipbuilding can generate substantial productivity improvement as demonstrated by our program results at BIW. Proven automation technologies are readily available and government programs are in place to provide the shipbuilder with both financial and technical support. Finally, the chance of automation program success can be greatly improved by fol1owing a few basic points in project development and control. The responsibility for increasing the level of automation in ship construction clearly rests with the shipbuilding industry.

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4. Editor, "Robot Safety; A Proposed Standard Details Guidelines," Industrial Safety and Hygiene News, December, 1984, page 15.

5. Everett, LCDR H.R., "Naval Sea Systems Command Integrated Robotics Program, Annual Report, FY-1984," NAVSEA Technical Report No. 450-90G-TR-0002, December, 1984, page 109.

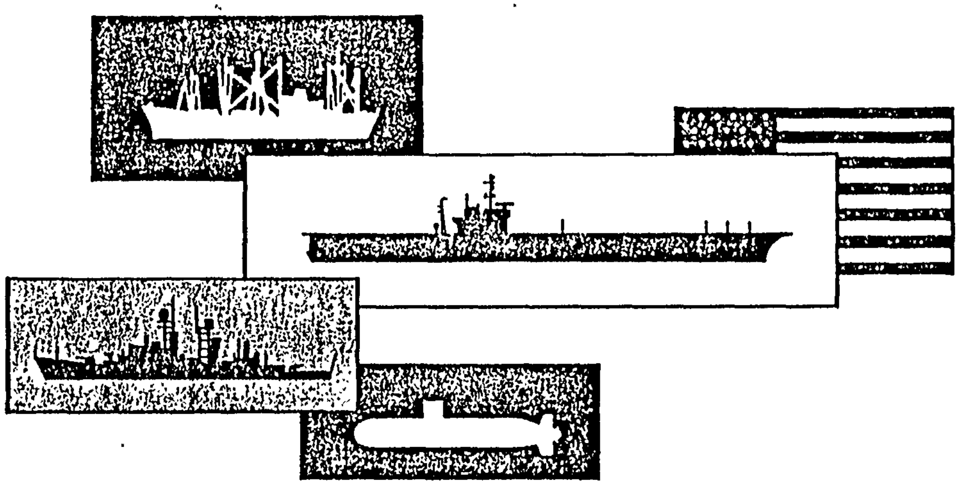
6. Ship Production Committee of the Society of Naval Architects and Marine Engineers, "National Shipbuilding Research Program Long-Range Productivity Plan," September, 1984, Section 3, page 6.

7. Bement, et al, "Statement of Principles for Department of Defense Manufacturing Technology Program," March 14, 1980.

8. Marine Equipment Leasing, Inc., "Technology Survey of Major U.S. Shipyards, Report of a Survey Made for U.S. Department of Commerce Maritime Administration," July, 1978, pp l-60.

FIGURES

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM LONG-RANGE PRODUCTIVITY IMPROVEMENT PLAN



PREPARED BY:

THE SHIP PRODUCTION COMMITTEE OF THE SOCIETY OF NAVAL ARCHITECTS & MARINE ENGINEERS

SEPTEMBER 1984

FIGURE 1

NAVSEA Technical Report
No. 450-90G-TR-0002

NAVAL SEA SYSTEMS COMMAND INTEGRATED ROBOTICS PROGRAM

ANNUAL REPORT
FISCAL YEAR 1984

OFFICE OF ROBOTICS AND AUTONOMOUS SYSTEMS
(SEA 90G)

DECEMBER 1984

Distribution limited to U.S. Government agencies and their contractors; material contains critical technology. Other requests for this document shall be referred to COMNAVSEASYSCOM or higher authority.

NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362-5101

FIGURE 2

BIW COMPUTER CONTROLLED SHEETMETAL FABRICATOR SKETCH

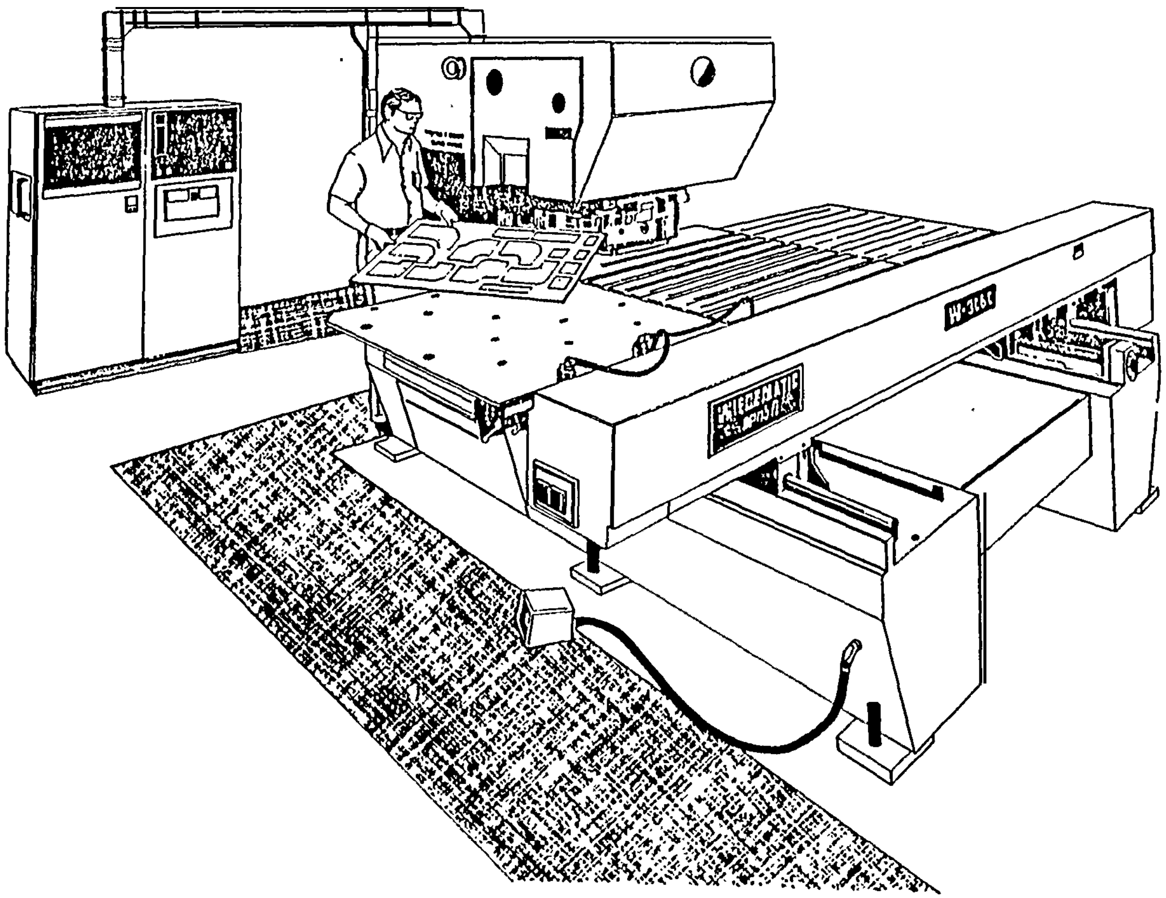
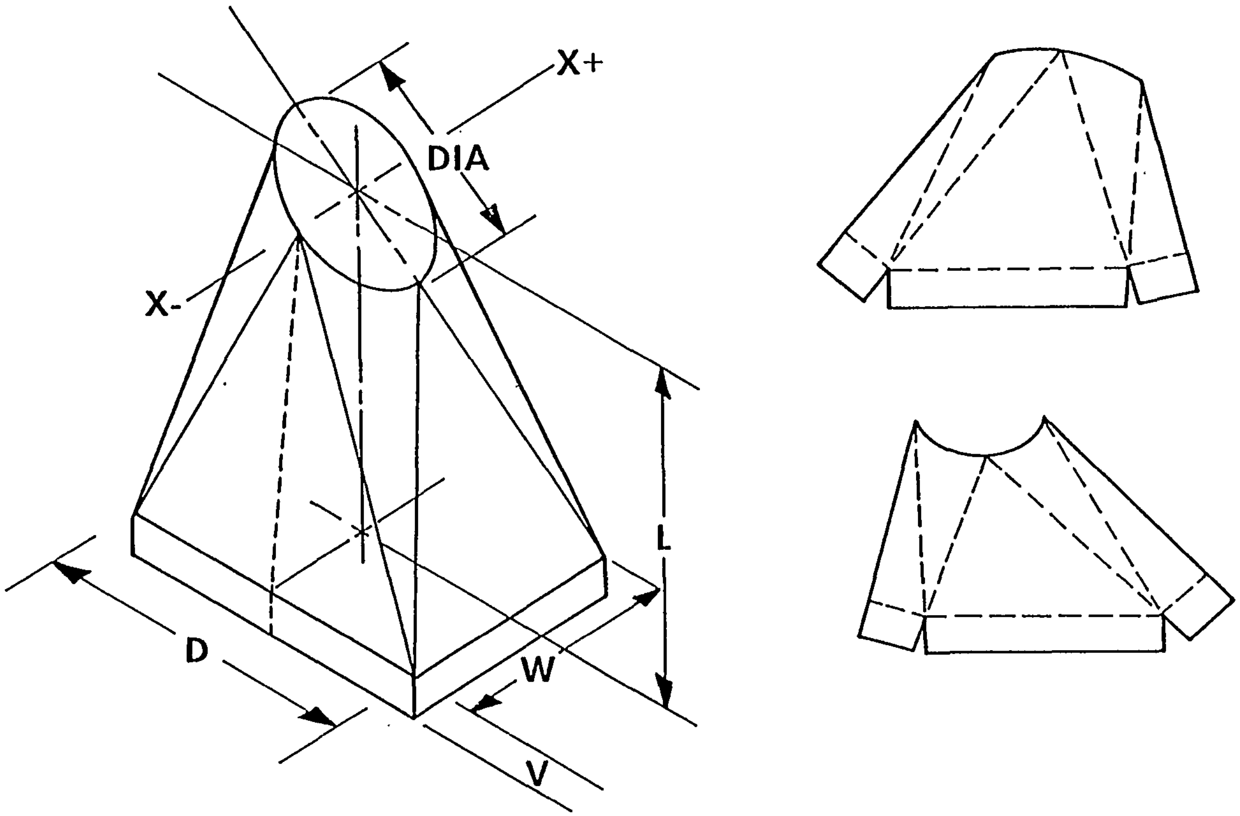


FIGURE 3

TYPICAL MARINE TYPE SHEETMETAL VENTILATION ASSEMBLY



TRANSITION - RECTANGULAR TO ROUND - SLANT TOP

FIGURE 4

GENERAL ARRANGEMENT OF ROBOTICS SHAPES PROCESSING SYSTEM

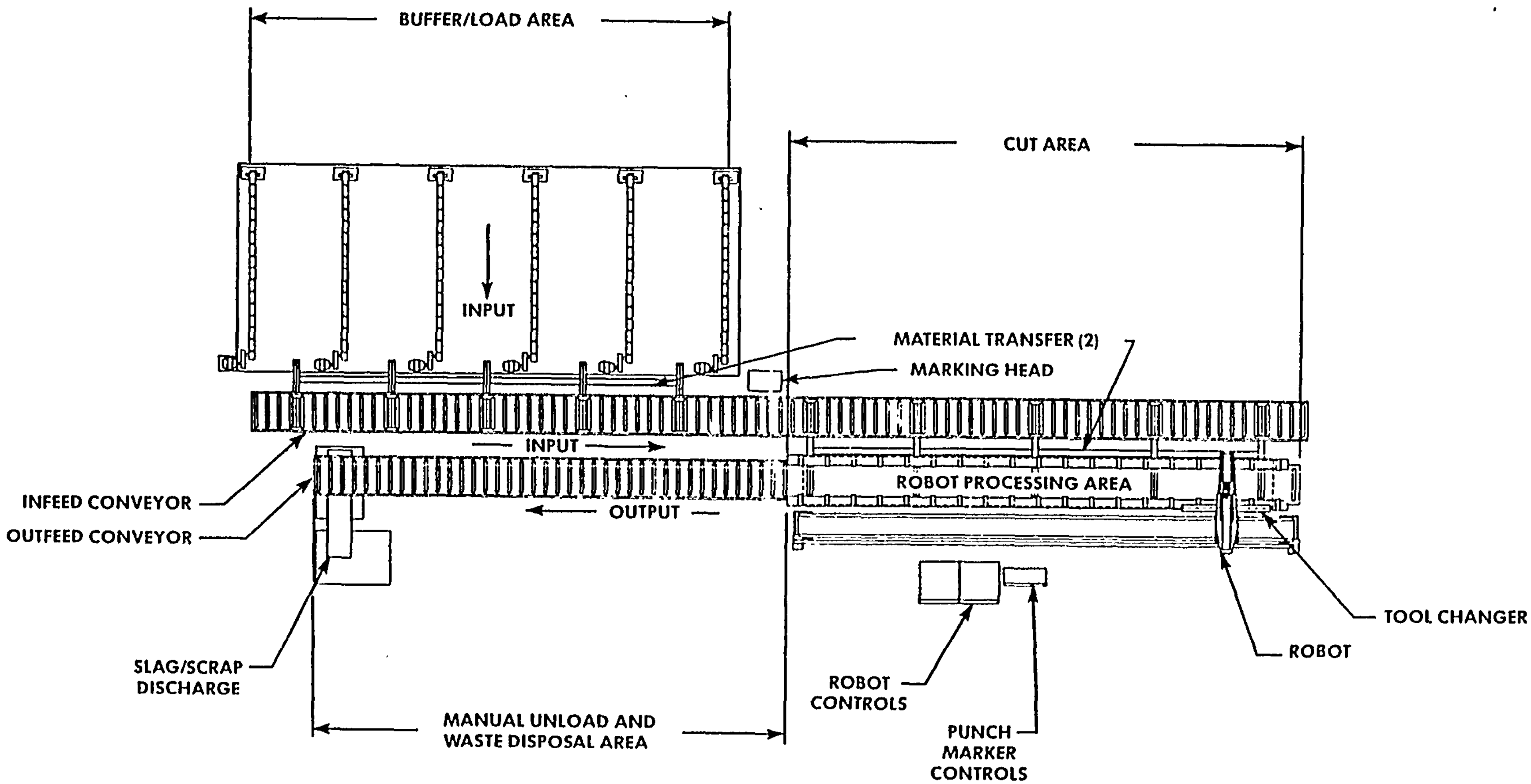
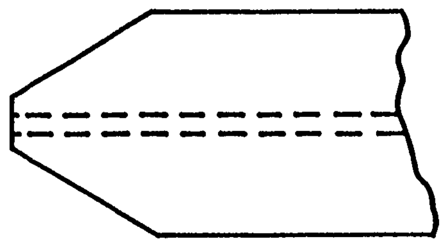
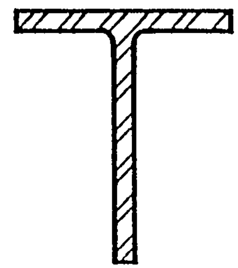


FIGURE 5

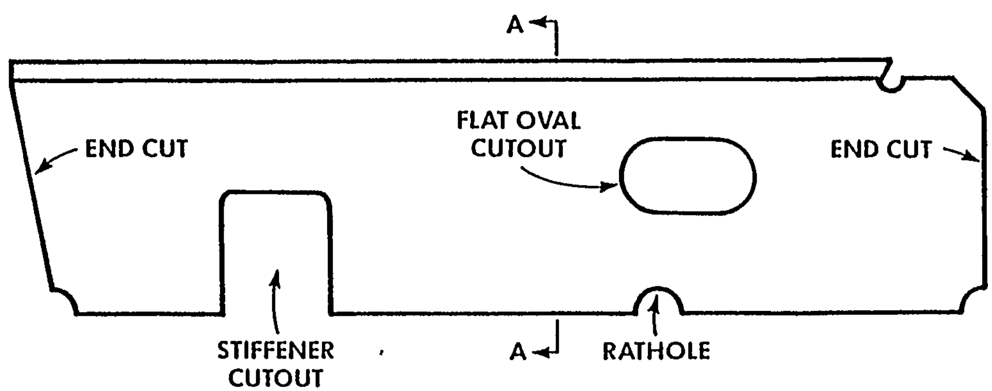
TYPICAL MARINE TYPE FABRICATED STRUCTURAL SHAPE



TOP VIEW



SECTION A-A



CUT TEE BAR

PRESENT AND PROPOSED SHAPES PROCESSING METHODS

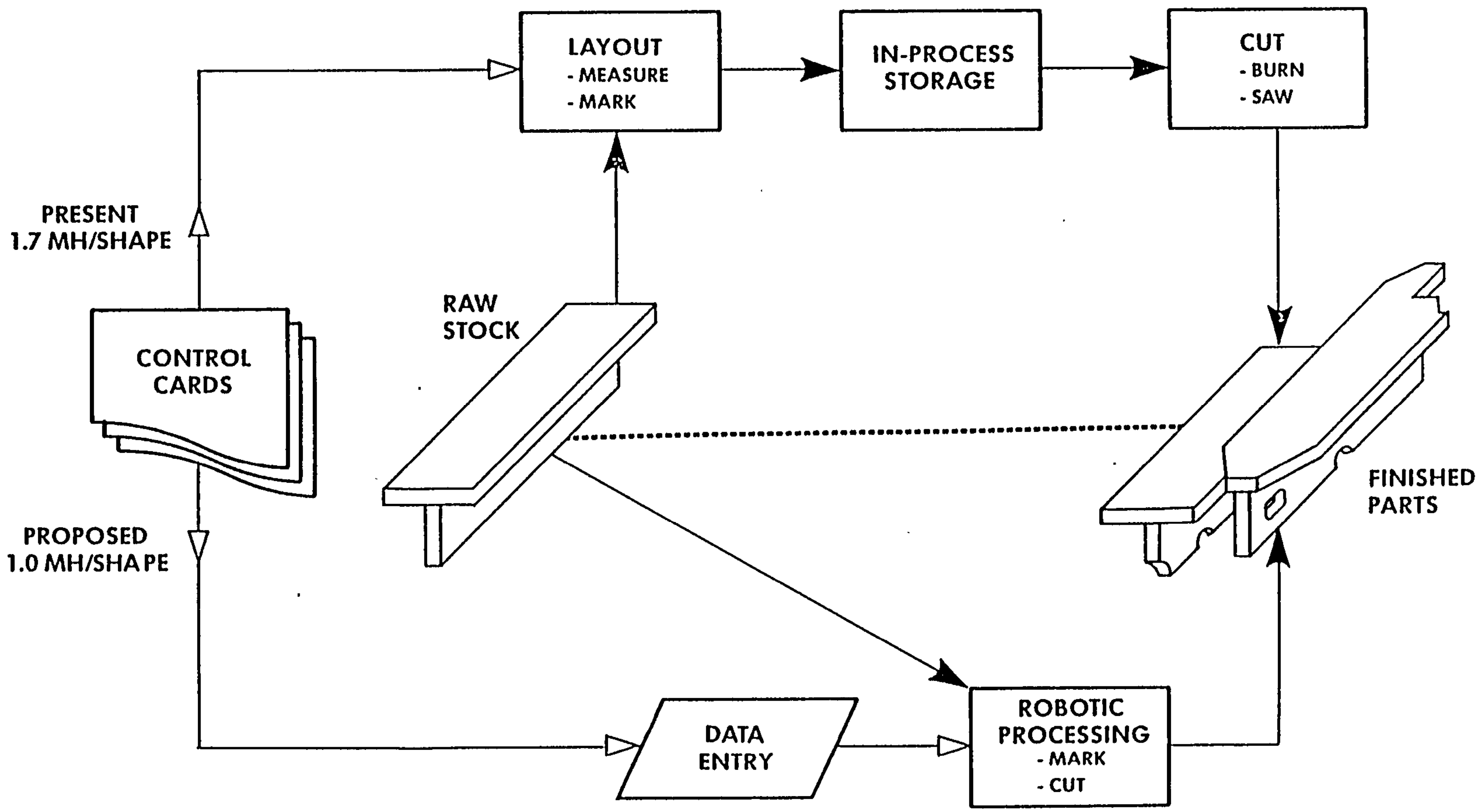


FIGURE 7

ROBOTICS SHAPES PROCESSING SYSTEM FLOW

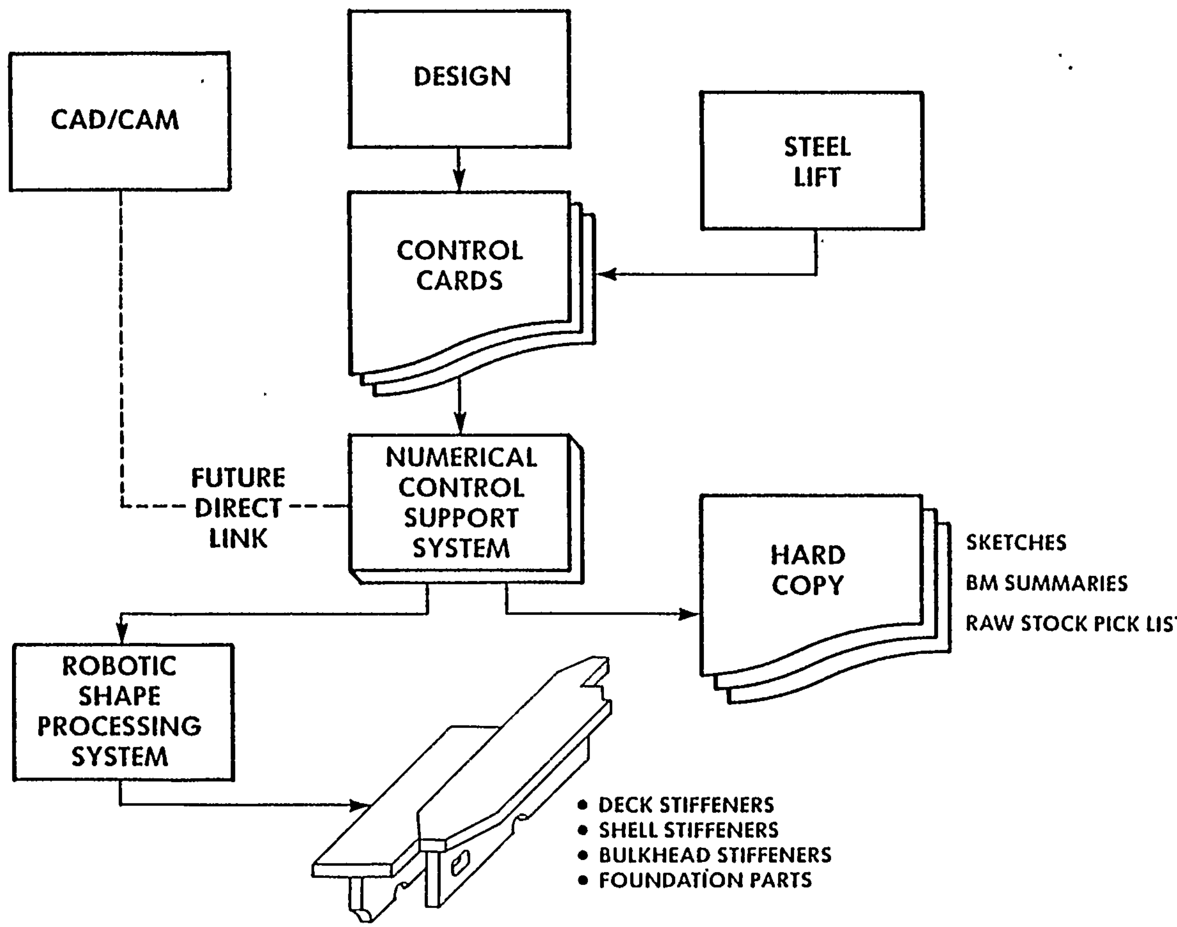


FIGURE 8

ROBOTICS SHAPES PROCESSING SYSTEM PROJECT SCHEDULE

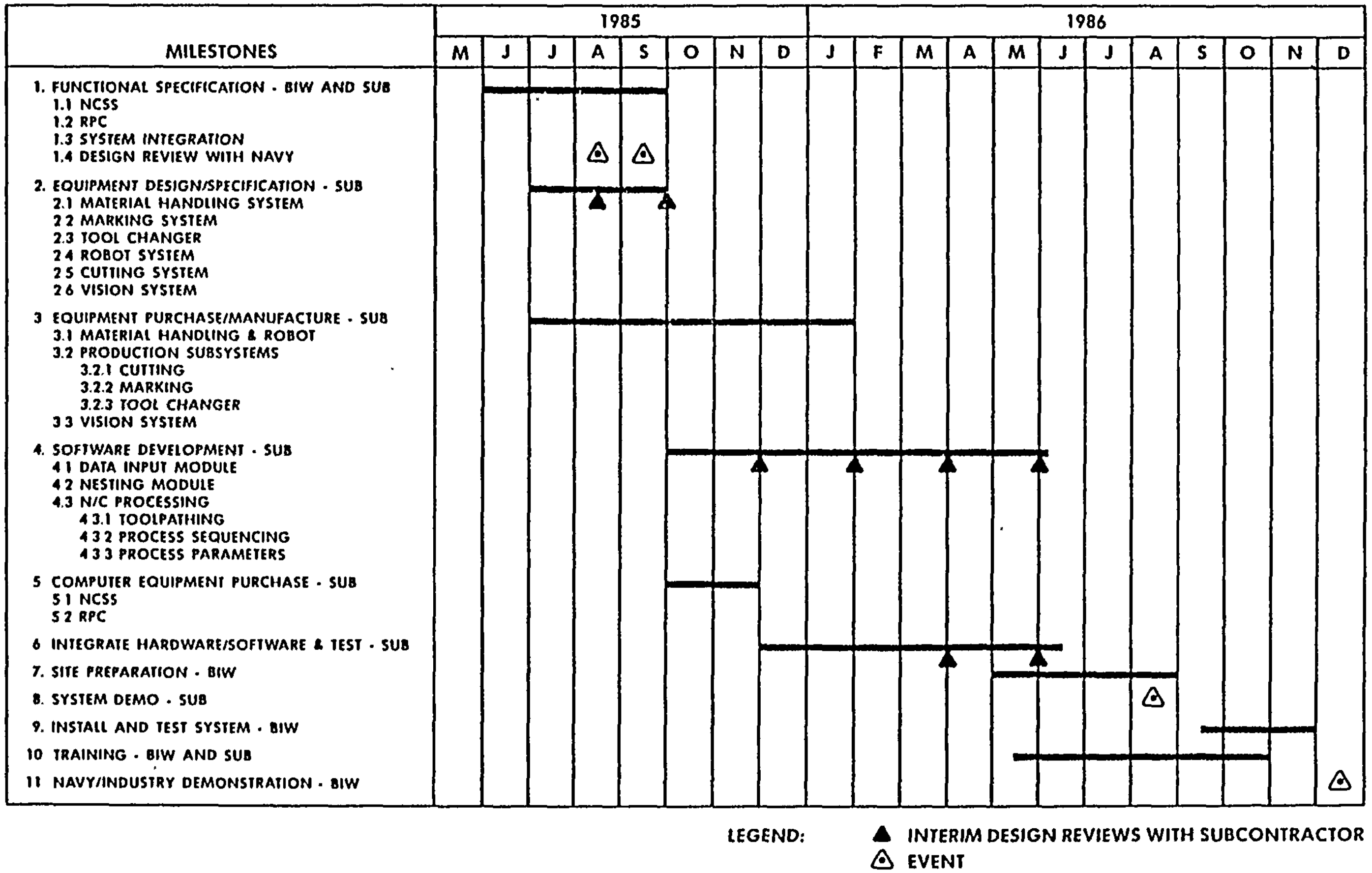


FIGURE 9

ROBOTICS SHAPES PROCESSING SYSTEM PROJECT ORGANIZATION

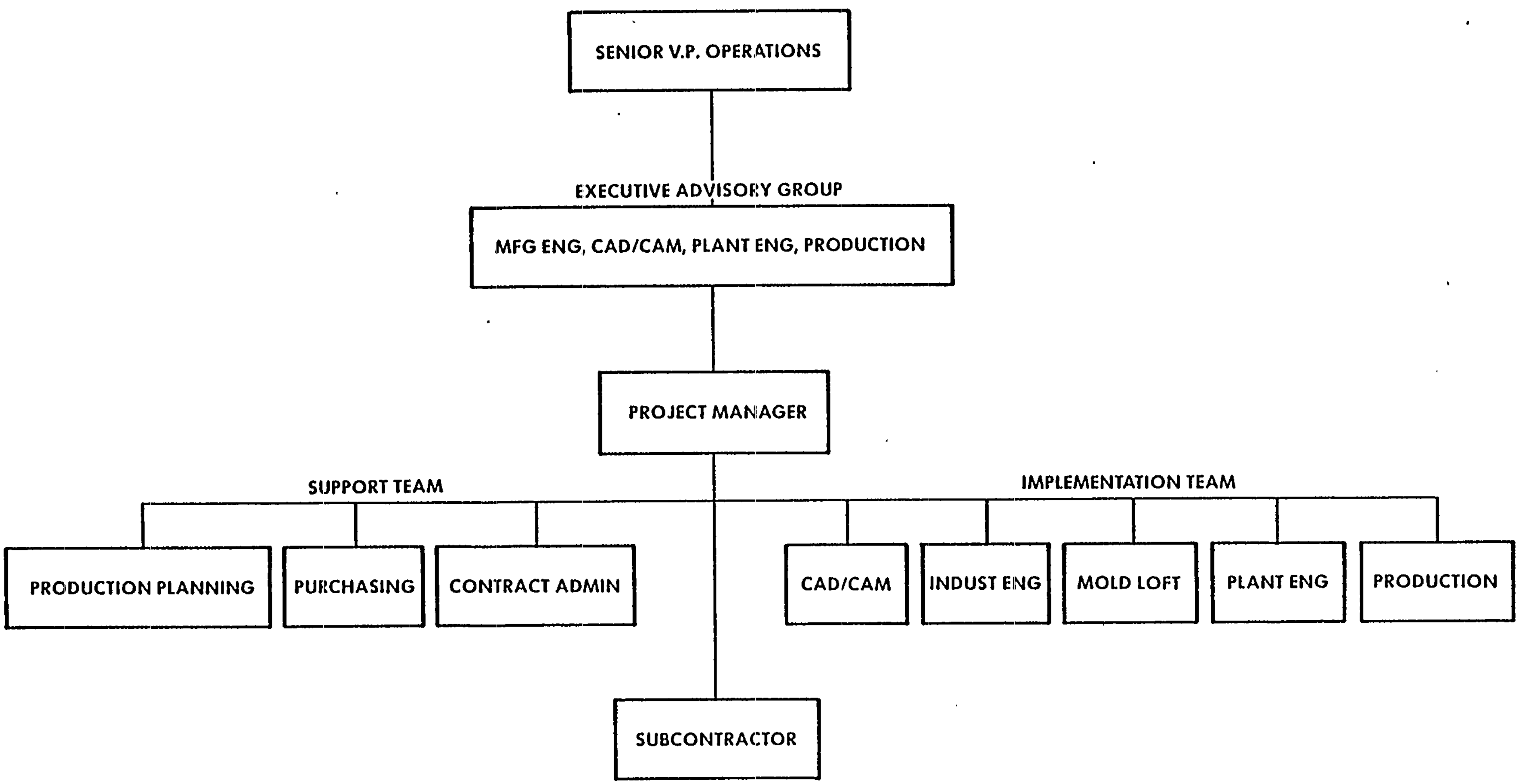


FIGURE 10

AVERAGE LEVELS OF TECHNOLOGY FOR THIRTEEN U.S. SHIPYARDS

	U.S. SHIPYARDS				
		NO. AT LEVEL			
STEELWORK PRODUCTION	AVG.	1	2	3	4
A1 PLATE STOCK YARD & TREATMENT	2.7	0	4	9	0
A2 STIFFENER STOCKYARD & TREATMENT	2.2	1	8	4	0
A3 PLATE CUTTING	3.5	0	0	7	6
A4 STIFFENER CUTTING	$\boxed{1.5}$	6	7	0	0
A5 PLATE & STIFFENER FORMING	2.2	1	8	4	0
A6 SUB-ASSEMBLY		2	5	6	0

OUTFIT PRODUCTION & STORES	AVG.	1	2	3	4
B1 PIPEWORK	2.0	1	11	1	0
B2 ENGINEERING	1.9	3	8	2	0
B3 BLACKSMITHS	3.9	0	0	1	12
B4 SHEETMETAL	$\boxed{2.1}$	2	8	3	0
B5 WOODWORKING	—	—	—	—	—
B6 ELECTRICAL	2.3	0	10	2	1

TABLE 1

COMPUTER OPTIMIZING OF BEVEL ANGLES

WELDED PIPE JOINTS

BY

Professor H.W. Mergler

Case Institute of Technology

ABSTRACT

The most common method for preparing the bevel-angle for welded pipe construction is to keep it at a constant value (say 37 degrees) around the entire periphery of the branch pipe. This paper explores the "optimized bevel-angle" as a function of pipe radii, wall thicknesses, centerline offset, and intersecting angle to keep the resulting weld cross section constant and thus minimize the weld volume while insuring' clearance for total weld penetration. The advantages of using the "optimized bevel angle" are demonstrated by computer simulation for pipe diameters from 4-l/2" to 24" for wall thicknesses over the range of 0.237" to 1.312". The ratio of the fixed bevel weld volume to the optimized bevel weld volume are shown to range from 1.5 to 5 which implies phenomenal reductions in the attendant welding time.

Computer Optimizing of Bevel Angles for Welded Pipe Joints

by

Professor H.W. Mergler
Case Institute of Technology

Introduction - This paper is based on the following statements:

1. Pipe joint welding times are directly proportional to the applied weld volume.
2. To optimize (minimize) the joint weld volume requires the preparation of the mechanical joint such that the bevel angle f3 of the branch component be optimized along its periphery as a function of the outside radii of the joint components R_m (main), and R_b (branch), the wall thickness of the branch T_b, the angle of intersection of the joint components 0, the offset of the centerlines of the joint components X_0, two practical boundary limits on minimum and maximum values of B dictated respectively by the destructive burning of the joint lip and torch accessibility for total weld penetration and the independent variable ϕ defining the position along the periphery of the branch where the local value of B is defined. These parameters are shown in Figure 1.

The implied calculation in (2) above is straight-forward though formidable. This paper will discuss the computations necessary to define the locus for the branch saddle as a function of the above mentioned variables as well as of the determination of the optimized bevel angle.

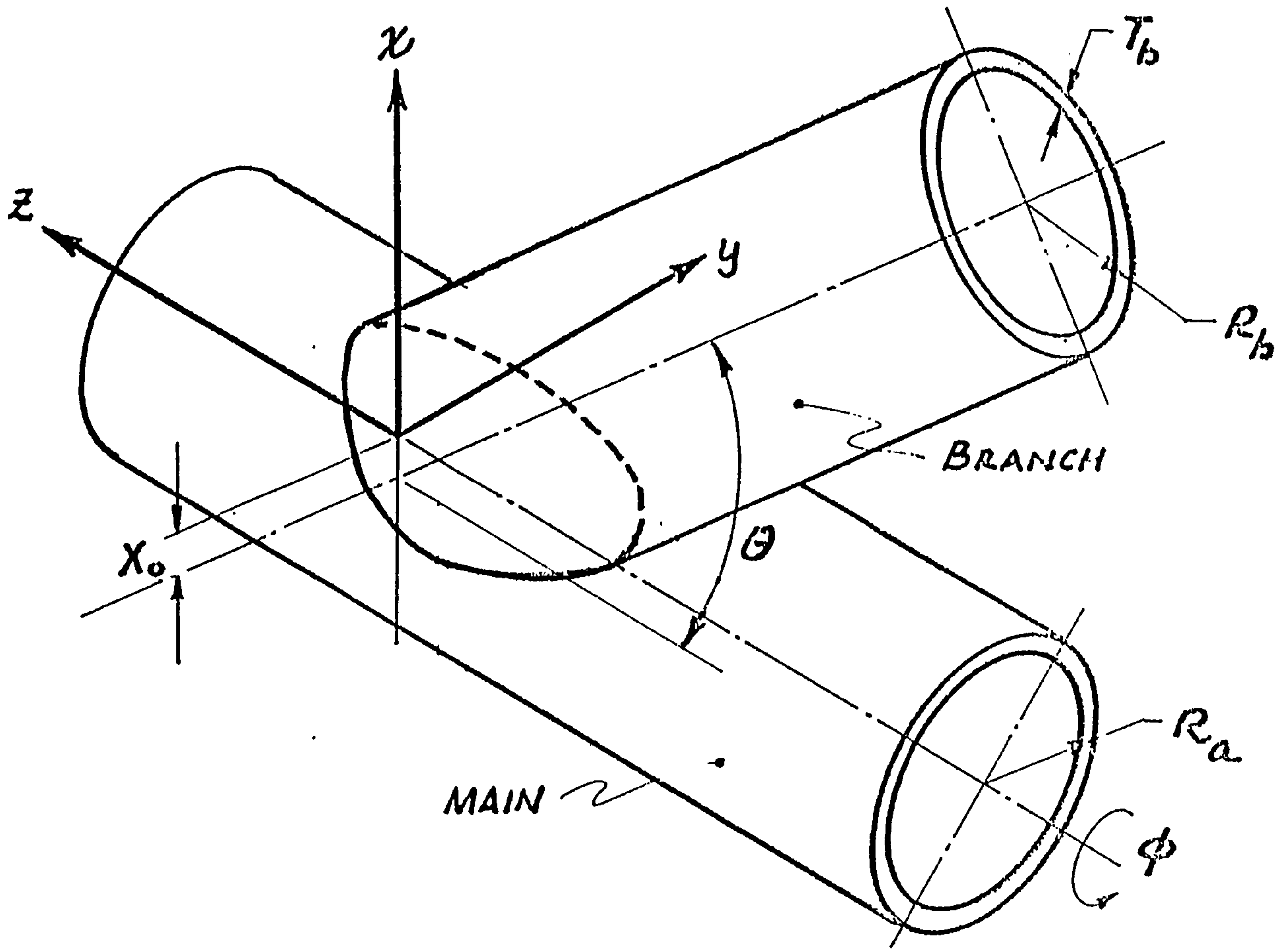


Figure 1. A Generalized Joint Configuration.

From these expressions the implied optimized weld volume may be determined and this weld volume will be shown to be dramatically smaller than those of pipe joints prepared with a constant bevel angle.

Symbols

- x,y,Z – a reference coordinate frame
- Z_b – a linear cylindrical coordinate (a function of Ø) defining the branch saddle profile
- R_a – the outside radius of the main component
- R_b – the outside radius of the branch component
- T_b – the wall thickness of the branch component
- X_o – the center line offset between the main and the branch
- θ – the angle between the main and the branch
- ϕ – the angle in a plane perpendicular to the branch centerline defining a line on the branch parallel to its centerline
- Y – the transformed coordinate ø
- A – the transformed coordinate X_θ
- D_a – the outside diameter of the main component
- D_b – the outside diameter of the branch component
- B – the bevel angle measured from the inner surface of the branch to the beveled surface
- D – the weld preparation included angle
- BEAN – the weld preparation angle being the complement of B
- L_1 – the length of the weld section adjacent to the beveled surface
- L_2 – the length of the weld section adjacent to the outer surface of the main component
- L_2 – the modified length of L_2

P_n - the area of the n^{th} weld section

P_M - the modified area of weld section

V_C - the weld volume with B = constant

V_o - the weld volume with B optimized

Computing the Space Trajectory (Locus) of the Intersection of Two Pines - The preparation of the mechanical joint of a main-branch pair may be thought of as three processes, the first two of which are done concurrently. They are

1. Preparation of the intersection profile on the branch
2. Preparation of the bevel angle along the profile of (1) above
3. Preparation of the saddle hole in the main

To develop the intersection locus (1) above consider a pipe joint with the following orientations shown in Figure 1.

1. The main component's centerline is coincident with the z axis and of radius R_a,
2. The branch component's centerline is parallel to the x-z plane and of radius R_b,
3. X_0 is the offset and is the x intercept of the branch's center-line on the X axis.
4. θ is the angle between the branch centerline and the x-z plane.
5. ϕ is independent variable measured around the z axis.

The resulting equation of the intersecting locus defined on the surface of the main component and expressed as a function of ϕ for fixed values of R_a, R_b, θ, and X_0 is

$$Z(\phi)) \quad R_a \cot\theta \sin\phi \pm |\csc\theta| \sqrt{R_b^2-(R_a \cos\phi - X_o)^2} \qquad (1)$$

Through coordinate translation the locus may be expressed in terms of the branch component as

$$z_b = R_b \cot(-\theta) \sin\phi \pm |\csc(-\theta)| \sqrt{R_a^2 - (R_b \cos\phi + X_o)^2} \qquad (2)$$

This (2) is the equation which describes the shape of the end of the branch for <u>proper</u> mechanical <u>profile</u> preparation of the joint. <u>It does not, however, address the nature of the bevel angle associated with this profile</u>.

<u>Computation of the Weld Cross Sectional Area</u> - The thrust of this paper is not the space trajectory of the intersecting surfaces as given by equations (1) and (2) but rather the determination of how to adjust the bevel angle on this trajectory to minimize the total weld volume.

Following a somewhat complex transformation[2] of coordinates and an integration over the range set by R_a and the wall thickness T_b a general expression for the weld area P may be derived as a function of y (the cylindrical angular coordinate around the z axis which is the axis of the branch component.

$$= \frac{T_b^2}{2}\cot\beta - \frac{T_b^2 \cos\gamma}{2\tan\theta} + \frac{T_b \cdot \sqrt{R_a^2 - [(R_b - T_b)\sin\gamma + A]^2}}{2\sin\theta}$$

$$+ \frac{(R_b \sin\gamma + A)}{2\sin\theta\sin\alpha}\left\{\sqrt{R_a^2 - [(R_b - T_b)\sin\gamma + A]^2} - \sqrt{R_a^2 - (R_b \sin\gamma + A)^2}\right\}$$

$$+ \frac{R_a^2}{2\sin\theta\sin\gamma}\left\{\sin^{-1}\left(\frac{R_b\sin\gamma + A}{-R_a}\right) - \sin^{-1}\left[\frac{(R_b - T_b)\sin\gamma + A}{-R_a}\right]\right\} \qquad (3)$$

Here A is the transformed offset X_0 in the original joint description.

Equation (3) is derived using a weld area bounded by the bevel surface of the branch, the surface of the main, and an extension of the outer surface of the branch to the main. A proper weld however strives to have both weld surfaces L_1 and L_2 be the same length. If $L_2 < L_1$' a point N Figure 2 will be moved to N' so that the length L_2 of N'I is equal to L_1. Figure 3 shows the general profile where $L_2 < L_1$. The point N is moved to a new position N' (y_1, z_1) on the ellipse so that L_2 of N'I is equal to L_1. The modified weld area P_M may be computed by making the following.substitutions in equation (3)'

$$T_b = T_{b'} = |Y_1 - y_o|$$

$$R_b = R'_{b'} = |Y_1| \tag{4}$$

Yielding a weld area P'. The area F of the triangle M'MN must then be subtracted from P' to get the new modified weld area with equal legs i.e. $L_1 = L'_2$.

Thus $$F(B) = 1/_2(T'_b - T_b) \quad (T_b' \cot B + (Z_o - z_1)] \tag{5}$$

and $$P_M = P' - F \tag{6}$$

<u>The Bevel Angle and Weld Preparation Angle</u> - Equation (3) may be rewritten to express the bevel angle as a function of R_b' T_b' A, o, P and the independent variable y as

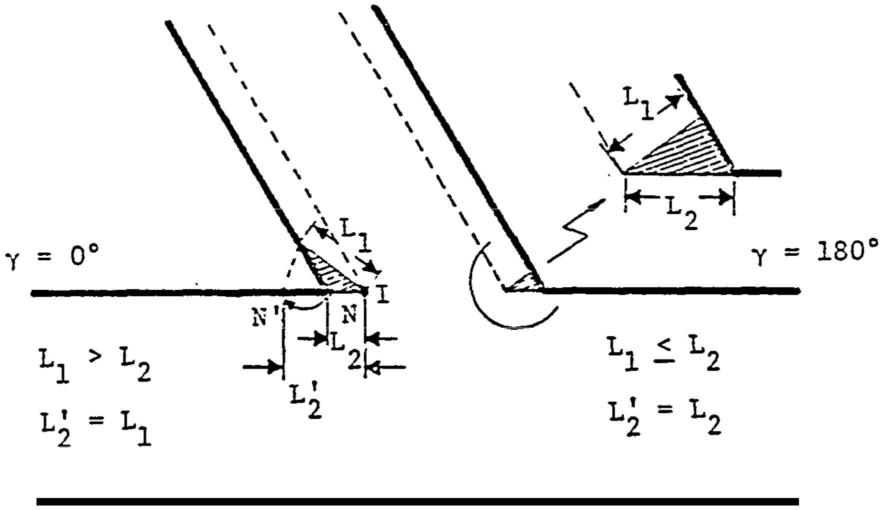


Figure 2. Modified Weld Areas in Pipe Joints for $6 \# 90^\circ$, and $y = 0^\circ$, 180°.

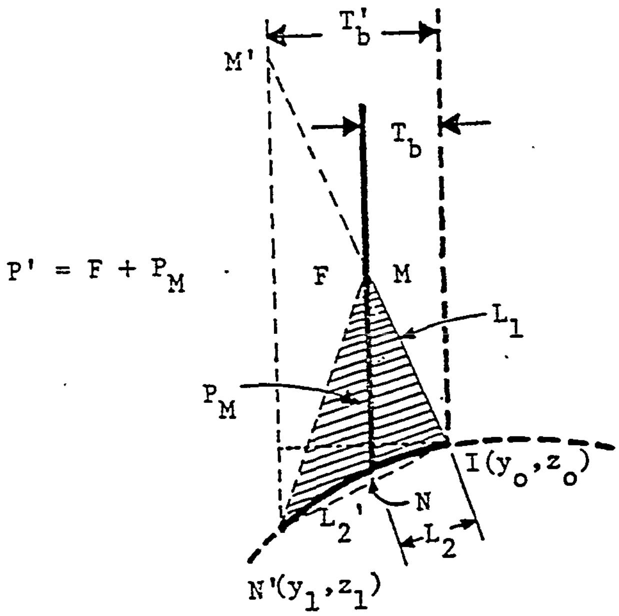


Figure 3. Intersection of the Modified Weld Area P_N in a General Profile for $L_2 < L_1$.

$$B = \cot^{-1}\left(\frac{2P}{T_b} - 2 + \frac{\cos y}{\tan\theta} - \frac{\sqrt{R_a^2 - [(R_b - T_b)\sin y + A]^2}}{T_b \sin 9} \right.$$

$$\frac{1}{T_b^2 \sin 9 \ \sin y} \left[(R_b \sin y + A)\{\sqrt{R_a^2 - [(Rb-Tb)\sin y + A]^2}\right.$$

$$- \sqrt{R_a^2 - (R_b \sin y + A)^2} \; 1 + R_a^2 \left(\sin^{-1}\left(\frac{R_b \sin y + A}{-R_a}\right)\right.$$

$$\left. - \sin^{-1}\left[\frac{(R_b - T_b)\ \sin Y + A}{-R_a}\right] \right]\Big\}\Big) \qquad (7)$$

Figure 4 shows this bevel angle 3 at two points on a typical branch. Of practical interest here are the limits placed on this angle. We designate the weld preparation angle as BEAN (the complement of B) as the angle of torch bevel measured from a line perpendicular to the surface of the branch pipe such that the wall will not be distorted by the torch heat. Experience indicates this should be no greater than 55° for plasma and 68° for.oxyacetelene. This maximum angle is designated DI in Figure 5. The-minimum angle (TI) of 37° (Figure 6) has been found to be the minimum angle to allow torch access to the joint to permit 100% weld penetration.

With these practical boundaries on the weld preparation angle we can compute the optimized weld volume (V_o) implied by the variable and optimized bevel angle and the fixed joint parameters R_a, R_b, T_b, 9, A around the branch-profile (expressed in the angle y).

The Weld Volume - From equation 3, which gives the localized weld area

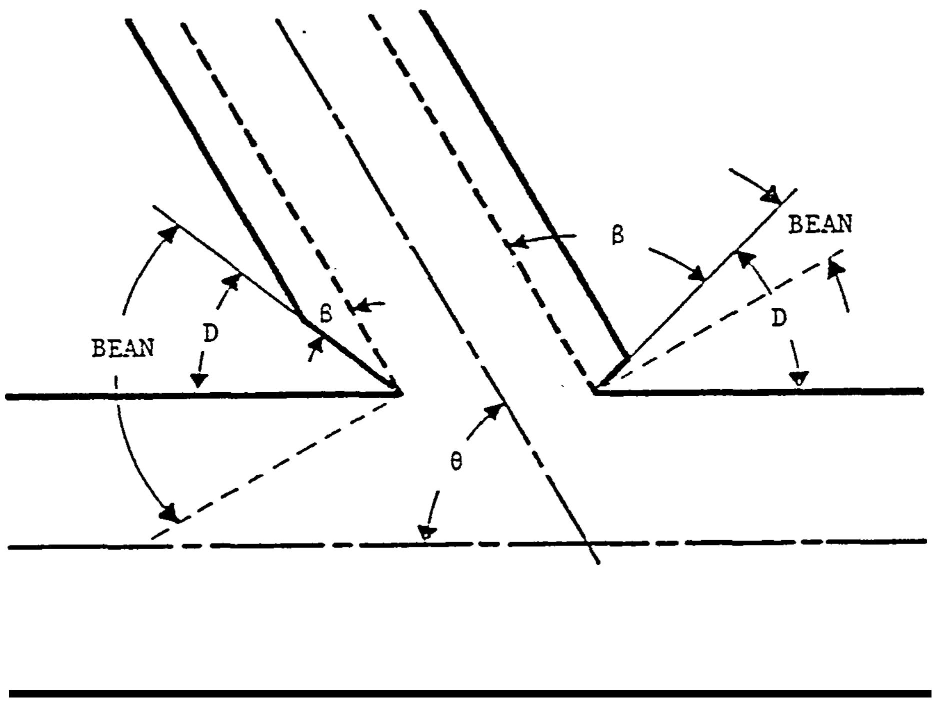


Figure 4. Interpretation of Bevel Angles BEAN, B Angles, and Weld Preparation Included Angles D.

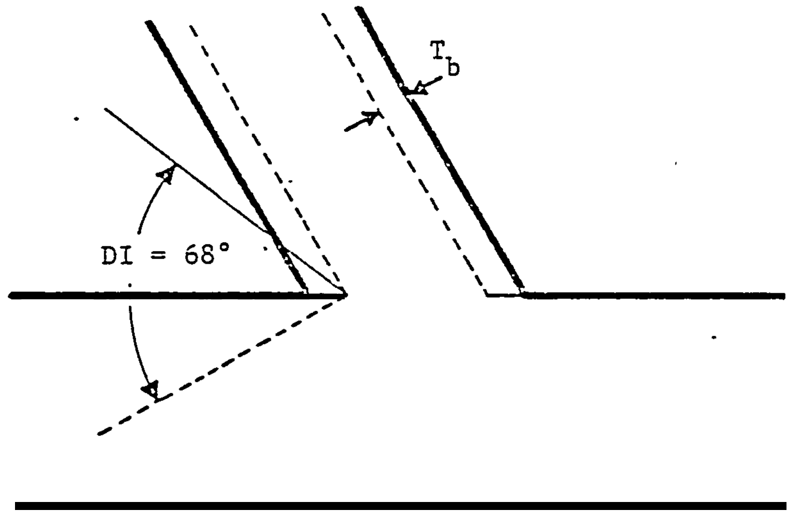


Figure 5. Maximum Allowable Bevel Angle DI in a Welded Pipe Joint.

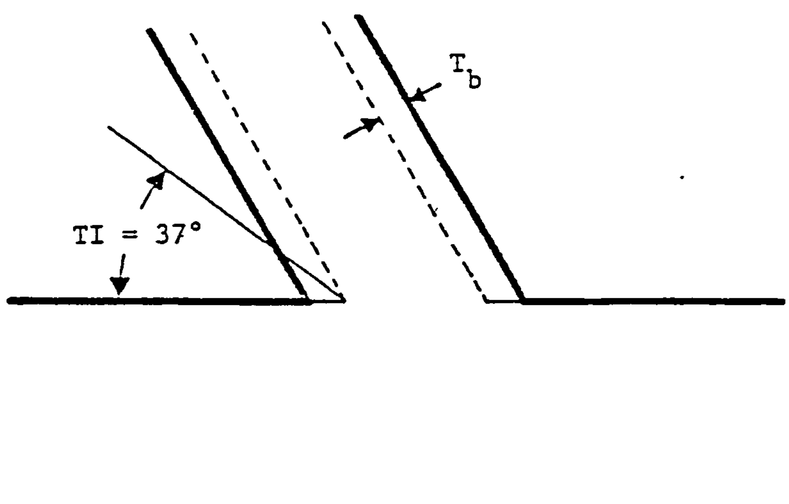


Figure 6. Minimum Allowable Weld Preparation Included Angle TI in a Welded Pipe Joint.

we may use numerical integration to compute the weld volume by the equation

$$\text{weld volume WEV} = \sum_{n=1}^{P} \frac{G\pi}{180} R_M P_n \tag{8}$$

where $n = 1, 2 \ldots \frac{360}{G}$

G = sample interval of y in degrees and $R_M = R_b + 1/3\,(T_B - 2T_b)$

<u>weld Volume for a Fixed Bevel Angle</u> - Figure 7 - The weld volume may be readily calculated with equation (8) using a constant value for B in equation (3). Here P_n is calculated for a constant B which is in turn dictated by the minimum weld preparation angle BEAN permitting 100 weld preparation. Here, (BEAN)CONSTANT is computed as

$$(\text{BEAN})_{\text{CONSTANT}} = D - (\text{TA})_{\text{MINIMUM}} \tag{9}$$

where D = say 37°

and $\text{TA}_{\text{MINIMUM}}$ = Minimum tangent angle which is the angle between a perpendicular to the interior wall of the branch and a line tangent to the main where the main is tangent to the branch interior wall.

<u>Weld Volume for an Optimized Bevel</u> - Figure 8 - Here we must first determine all tangent angles around the circumference of the branch. Then each optimized weld preparation angle $(\text{BEAN})_n$ equals the included angle D minus the local tangent angle $(\text{TA})_n$.

i.e. $$(\text{BEAN})_n = D - (\text{TA})_n \text{ where } n = 1,2,\ldots\ldots \frac{360}{G} \tag{10}$$

Thus, as the tangent angle changes, the corresponding bevel angle changes

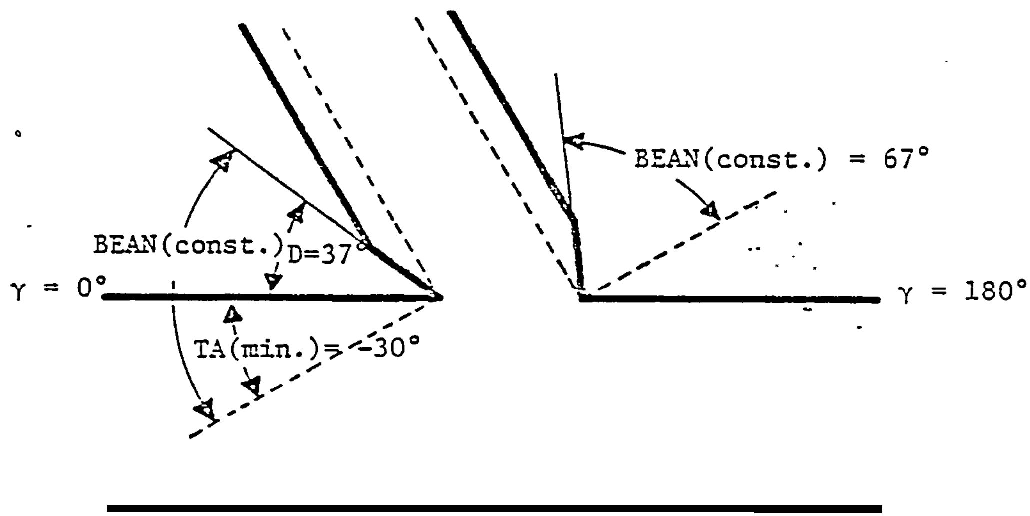


Figure 7. Profile of the Pipe Joints with Fixed Bevel Angle.

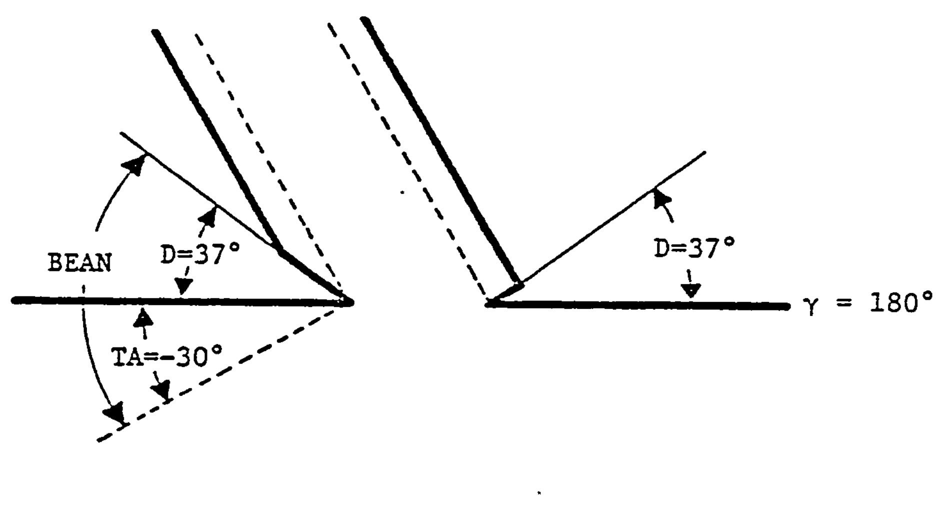


Figure 8. Profile of the Pipe Joints with Optimized Bevel Angle.

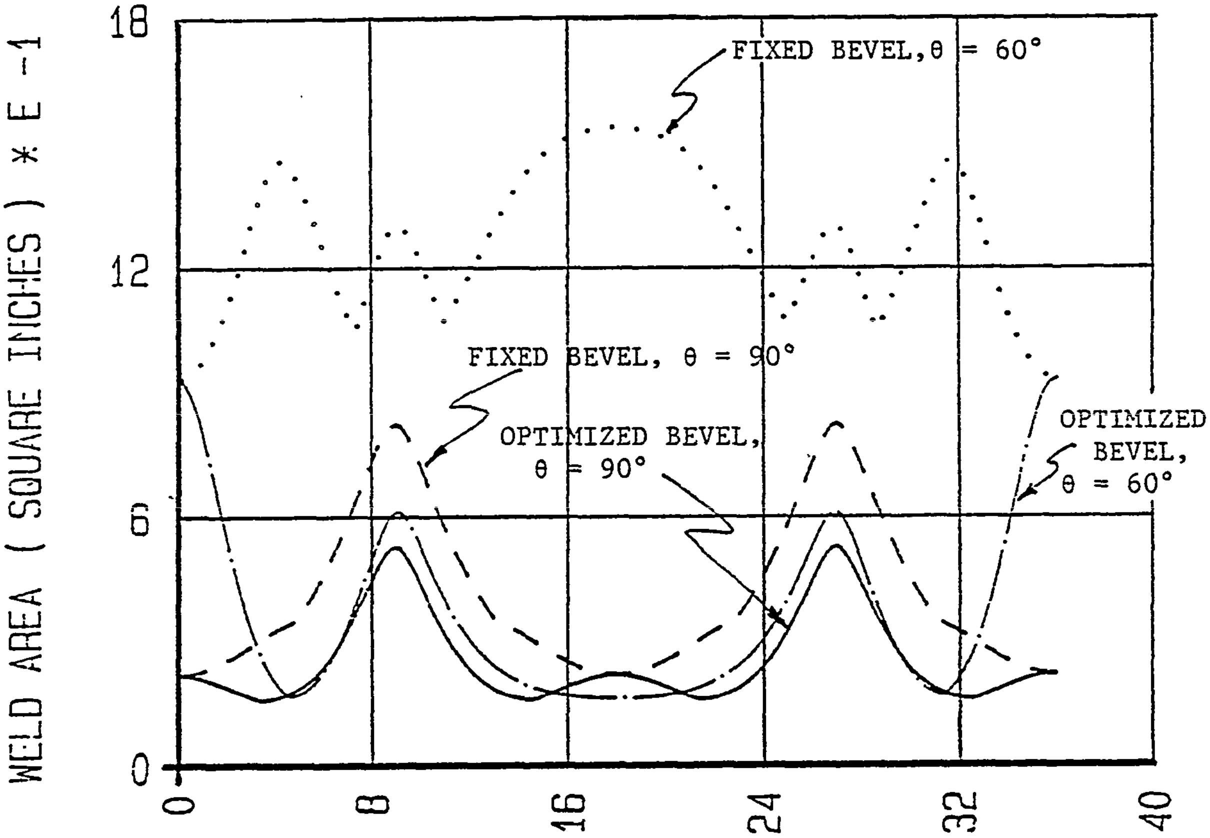
Table I - Weld Volume Comparison for Selected Joint Sizes and Configurations

D_a INCHES	$Sched_a$	D_b INCHES	$Sched_b$	T_b INCHES	θ DEGREES	V_C IN^3	V 03 IS
4.5	40	4.5	40	.237	90	.681	.420
	40		40	.237	60	2.124	.597
	80		80	.337	90	1.275	.789
	80		80	.337	60	4.184	1.142
	120		120	.438	90	2.023	1.262
	120		120	.438	60	6.915	1.859
	160		160	.531	90	2.828	1.784
	160		160	.531	60	9.975	2.667
	DBL.E.H.		DBL.E.H.	.674	90	4.255	2.742
	DBL.E.H.		DBL.E.H.	.674	60	15.614	4.192
6.625	STD.40	6.625	STD.40	.280	90	1.461	0.093
	STD.40		STD.40	.280	60	4.431	1.272
	80		80	.432	90	3.182	1.964
	80		80	.432	60	10.229	2.823
	120		120	.562	60	5.072	3.147
	120		120	.562	90	16.958	4.592 ,
	160		160	.719	60	7.805	4.897
	160		160	.719	90	27.154	7.271
	DBL.E.H.		DBL.E.H.	.864	60	10.719	6.817
	DBL.E.H.		DBL.E.H.	.864	90	38.451	10.279
8.625	STD.40	8.625	STD.40	,322	90	2.575	1.596
	STD.40		STD.40	.322	60	7.693	2.237
	80		80	.500	90	5.691	3.510
	80		80	.500	60	17.992	5.015
	120		120	.719	90	10.853	6.730
	120		120	.719	60	36.118	9.810
	160		160	.906	90	16.272	10.191
	160		160	.906	60	56.307	15.093
	DBL.E.H.		DBL.E.H.	.875	90	15.314	9.572
	DBL.E.H.		DBL.E.H.	.875	60	52.690	14.141

D_a INCHES	$Sched_a$	D_b INTCHES	$Sched_b$	T_b INCHES	θ DEGREES	V_C IN^3	V_{03} 13
12.750	STD	12.750	STD	.375	90	5.391	3.362
	STD		STD	.375	60	15.669	4.671
	40		40	.406	90	6.231	3.876
	40		40	.406	60	18.272	5.401
	60		60	.562	90	11.235	6.941
	60		60	-562	60	34.254	9.797
	80		80	.688	90	16.169	9.972
	80		80	,688	60	50.616	14.201
	120		120	1.000	90	31.481	19.487
	120		120	1.000	60	103.994	28.303
	160		160	1.312	90	50.712	31.723
	160		160	1.312	60	174.886	46.911
	DBL.E.H.		DBL.E.H.	1.000	90	31.481	19.487
	DBL.EeH.		DBL.E.H.	1.000	60	103.994	28.303
16.	80	16.	80	.844	90	30.678	18.921
	80		80	.844	60	95.744	26.917
	160		160	1.594	90	94.713	59.151
	160		160	1.594	60	324.915	87.264
20.	80	20.	80	1.031	90	57.493	35.464
	80		80	1.031	60	178.880	50.397
	160		160	1.969	90	181.190	113.093
	160		160	1.969	60	620.392	166.703
24.	80	24.	80	1.219	90	96.737	59.676
	80		80	1.219	60	300.392	84.747
	160		160	2.344	90	308.753	192.642
	160		160	2.344	60	1055.813	283.798
8.625	80	4.5	80	.337	90	.921	.600
8.625	80	4.5	80	-337	60	4.737	.975

D_a INCHES	$Sched_a$	D_b INCHES	$Sched_b$	T_b INCHES	θ DEGREES	V_{C} IN^3	V_{03} IN^3
12.750	80	6.625	80	,432	90	2.245	1.455
12.750	80	6.625	80	.432	60	11.473	2.354
16	80	8.625	80	.500	90	3.964	2.542
16	80	8.625	80	.500	60	19.996	4.067

PIPE SIZE:12; N: 80; SIZE ON SIZE



GAMMA (DEGREES) E 1

The Weld Areas around the Branch Pipe Circumference
for DA = DB = 12.75 in. and TB = 0.688 in.

accordingly, while the weld preparation included angle D remains constant.

The implied local optimized bevel angle derived from equation (10) is then used in equations (3) and (8) to give the optimized weld volume.

Conclusions - FORTRAN computer programs have been written to execute all computations implied by the preceding discussion. One hundred and twenty different joint configurations were studied for weld area variations for both fixed and optimized bevel angle configuration The studied cases included size on size and differing diameters, intersecting angles of 60° and 90°, offsets, pipe sizes from 4 inches to 24 inches and schedules from 40 to 160.

All cases studied showed a dramatic reduction in weld volume when the optimized volume (V_o) was compared to that (V_c) obtained using a fixed bevel angle. The results of this weld volume comparison are shown in Table I.

The results of this comparison are so dramatic that modification of current yard practice in the mechanical preparation of welded pipe joints must be given consideration. Existing pipe fabrication machinery may be realistically modified to permit this optimization and cost recoveries achieved using fabricated joints vs. the use of prefabricated couplings can be demonstrated to be rapid and persuasive.

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APPLICATION OF FLEXIBLE AUTOMATION TO SHIP CONSTRUCTION

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ABSTRACT

Computer-aided design and flexible automated manufacturing technologies presently available and currently under active development can provide the keys to improved productivity in shipbuilding. The specific applications of these technologies, implemented or proposed for other more structured and product-form stationary industries, are not generally applicable to shipbuilding. The problem addressed by this project is the research and analysis of the potential mating of advanced productivity improvement technologies to shipbuilding. Formal criteria are proposed for the selection of ship construction operations and the establishment of their priority as candidates for further study of automation potential.

INTRODUCTION

The concept of applying flexible automation for productivity improvement is widely accepted throughout many metals-working industries. Applications of these technologies are, however, just beginning to emerge in ship construction. This is largely due to the differences in the workpieces and workplace existing between ship construction and other metals-working industries. Lists abound of ship construction processes suggested as candidates for automation. Relevant criteria are needed to make rational choices in ordering the candidates. It is not surprising that the criteria developed for other metals-working industries are not strictly applicable to ship construction.

Selection criteria commonly proposed in robotics literature are examined with respect to the particular characteristics of ship construction. On the basis of this discussion, certain of these criteria are rejected as inappropriate or insensitive in the ship construction environment. Additional criteria with particular applicability to ship construction are proposed. Automation opportunities are plentiful and shipbuilder's resources are limited. The question is how to decide the best places to invest time and capital.

We can, however, develop an applicable set of criteria by examining the constraints and realities of the ship construction industry.

ECONOMIC FACTORS FAVORING FLEXIBLE AUTOMATION

Present and foreseeable future world realities facing the United States make it imperative that shipbuilders supply to the Navy evermore capable ships at evermore improved acquisition costs. Much of the acquisition cost of a ship is beyond the direct control of the shipbuilder. The cost of material, machinery, equipment, and weapon systems is largely determined by the suppliers. The unit cost of labor to complete the contract

design, acquire the material, and construct the ship is related to the prevailing wage for similar work. What the shipbuilder can control is the effectiveness with which material is used and labor is expended in realizing the completed ship.

Traditional organization of ship planning, design, construction, and testing is established along the boundaries of structural and functional systems that comprise the ship. The form of organization evolved in parallel with the evolution from simple hulls to modern surface combatant ships. Masts were stepped into simple hulls. Bulkheads and decks were incorporated to improve the ship structure. Cuddies and then deckhouses added accommodation for the ship company. These examples and many more have direct evolutionary counterparts in a modern ship; each separately conceived and established. The strength of this form of organization is the visibility of individual systems and the ease of monitoring the progress of these systems toward completion. The traditional organization, however, forces the shipbuilder strictly to adopt job shop methods and to accept the inefficiencies that attend that way of doing-work.

Many shipbuilding methods are the evolutionary result of something that was tried in the past and adopted simply because it worked. The issue is complicated by the very large size and mass of a ship and by the multitude of machinery, equipment, and functions that must be incorporated in the ship. During a ship construction cycle, the requirements of a ship can change and technical development may offer the opportunity for improved ship capabilities. Only a small amount of the work is exactly repeated, even between ships for the same class. Thus, shipbuilding is a highly unstructured and very labor intense industry.

Foreign shipbuilders have provided ample evidence that significant' productivity gains can be achieved for certain classes by a form of organization that disaggregates the ship along construction boundaries. This procedure is repeated to achieve ever simpler parts with ever reduced geometric, material, and manufacturing processes individually. In accomplishing this procedure, great volumes of information are created and exchanged among

the ship owner and the shipbuilder's operating organizations. Finally, families of similar parts are fabricated using repeatable manufacturing processes and suitable fixtures to achieve the accuracy required for assembly into the ship. The gains of this procedure are realized by taking advantage of the production economies of scale.

During the previous two decades, many of the manufacturing concepts perfected in foreign yards have been adopted in modified form to suit local conditions by shipbuilders in the United States. Disaggregation of a complex surface combatant ship to a level supporting parts fabrication on fixed tooling remains, however, a very large and difficult task. Because of the complexity of these ships, clearly any manufacturing procedure used to fabricate the required components will necessarily be data-driven.

Computer-Aided Design and flexible automated manufacturing technologies presently available and currently under active development can provide the tools for improved productivity in shipbuilding. The specific applications of these technologies, implemented or proposed for other more structured and product-form stationary industries are, however, not generally applicable to shipbuilding.

SHIP CONSTRUCTION FACTORS DISCOURAGING FLEXIBLE AUTOMATION

Having described the economic factors favoring the introduction of flexible automation in ship construction, it is also necessary to describe the factors discouraging the introduction of these technologies. The list of discouraging factors given here is not new. All of the factors in this list have appeared in one form or another in previous papers [l]. Each of these discouraging factors must be addressed by any successful. application of flexible automation to ship construction.

Ships are generally built on a one-off basis or in small classes of a given type. Larger classes are usually comprised of several subclasses, each subclass differing significantly from the others. Production runs of standard ships are rare. Even within a specific ship,

the utilization of duplicate parts is very low. Foundations, piping assemblies, and structural assemblies tend to be individually designed to accommodate local details within the ship.

In addition to the use of few parts that are duplicated many times throughout a ship, ship designs tend to be geometrically very complex and to provide confined access to much of the work. Much of this could be relieved, at least conceptually, through redesign of the ship. This would require a radical reappraisal of design criteria and objectives. This would also likely require resolution of numerous conflicts with Navy specifications and the design rules of the classification societies.

Ship parts and assemblies tend to be large when compared with industrial robots. Ship parts and assemblies tend to be approximately planar, or boxlike. These shapes mate poorly with the spheroidal working envelopes of many industrial robots. The dimensional tolerances of ship parts and the low precision with which they are placed onto each other are difficult to accommodate with existing robot controllers. What is needed are flexible automation systems specifically developed and suited for ship construction. This development will be costly and require significant time to accomplish. For this reason, custom ship construction flexible automation systems may be difficult to economically justify.

In isolation, many ship construction operations are technically feasible. For flexible automation, parts presentation tooling and extra handling may be required, both upstream and downstream of the automation station. These costs may exceed the benefit achieved. The investment in isolated automation can preclude the economic viability of developing a broader ’ system encompassing adjacent operations.

There are very finite bounds to the flexibility which can be obtained with any production automation system. These systems will always be limited to functioning in the specific class of production situations for which they are designed. A craftsman possesses far greater adaptability and is provided with many more degrees of mechanical freedom than any

mechanical production **system.** The strength, speed, endurance and exactness of a craftsman are limited. The nature of ship construction operations necessitates a continuing concert working relationship between craftsmen and flexible automation systems. Craftsmen cooperatively functioning in concert with flexible automation systems cannot be subjected by the system to unacceptable levels of hazard.

Viewed in total, the factors discouraging flexible automation.in ship construction are the expression of four very real concerns:

Reduction of the economic benefit of the flexible automation system due to the programming costs associated with large numbers of differently configured parts and confined access.

Economic justification of the greater investment required to develop flexible automation truly suitable to ship construction.

Reduction of the economic benefit of the flexible automation system due to additional facility and special practices, particularly part presentation tooling and part, required as a consequence of mechanization.

Availability of adequate personnel safety measures which are technically and economically feasible.

BASIS FOR ESTABLISHING EVALUATION CRITERIA

Certain flexible automation systems proposed for ship construction will be feasible in the sense that the required development can be accomplished with technology’available currently or anticipated in the immediate future. Some can be made adequately safe in the sense that technically and economically feasible measures to limit the hazard to crafts**men** functioning in concert with the system are available. Some will be useful in the sense that system operation accomplishes manufacture of ship subproduct or class of subproducts without undue disruption upstream or downstream. Some will be potentially profitable in

the sense that the productivity improvements and other benefits anticipated as a result of system operation return the necessary investment in a manner attractive to the owners.

Clearly, successful flexible automation systems must belong to the subset of feasible proposals which are co-jointly adequately safe, useful, and potentially profitable.

Given the limited availability of resources, criteria are needed to rationally establish priorities for development. Many such criteria, appropriate for factory situations, have been proposed in the literature of flexible automation. The constraints of ship construction force modification of these criteria. The resulting modified criteria are no longer quite as simple or straightforward to apply, but realistically account for factors unique to shipbuilding.

The modified criteria may be used in a qualitative analysis or 'an approximate qualitative analysis as a linear combination of weighted factors. Since some of the modified criteria embody complex concepts, a level of uncertainty may exist in measuring proposed flexible automation systems under these criteria. Utility theory includes the computational tools for an exact analysis in the presence of uncertainty. An explanation of these computational tools is beyond the scope of this discussion.

ERGONOMICS

Reduction of negative ergonomic factors associated with current production methods are prominent among factory automation project evaluation criteria. These include reduction of hazard to personnel, strenuousness and tedium. These .factors lead to unacceptable accident rates, absenteeism, employee turnover, and rework. Such things are proper concerns of shipbuilders; however, use of these criteria tacitly presumes wide variation in negative ergonomic factors with relatively uniform difficulty and technical feasibility of automation. With ship construction operations strenuousness is relatively uniform. Job details change daily and tedium in the factory sense does not exist. Hazardous ship construction jobs

such as working inside tanks and voids are most often associated with the most highly unstructured work environment and are therefore the least technically feasible for automation. These criteria are not sensitive indicators of the merits of ship construction automation projects.

FEASIBILITY

Contrary to popular..belief, the feasibility of flexible automation projects is not just a binary proposition of .feasible and infeasible. Between the extremes of impossible and assured, there are innumerable shades of grey, ranging from difficult to easy. Different configurations to resolve the technical objective may have very different feasibility.

Establishing technical feasibility of factory flexible automation projects involves identifying manipulation machines which have a sufficiently large working envelope, are capable of the necessary motions and precision, and are rated for the necessary payload. Factory flexible automation projects are often a direct replacement for manual operations and the process tools used are a direct extension of the process tools used in the manual operation. Parts handling equipment and even the necessary sensor systems are generally available as commercial items. The areas of primary technical risk are achieving critical part alignments and avoiding manipulator collisions.

DEXTERITY

Ship construction adds the dimension of scale, adaptivity, and rapid product variation to consideration of technical feasibility. The dexterity and precision of tool motion required with respect to a large scale ship construction is the same as required for much smaller workpieces. The working envelope necessary is far beyond the capabilities of commercial robots. A very large special design robot is required to manipulate the tool over the workpiece, or else a secondary means of positioning a smaller robot over a local worksite is required. Manipulation machinery of this size can vibrate the tool through greater distances

than the process tolerances. Additionally, the fundamental and low order harmonic frequencies of the large links impose new constraints on the selection of system control frequencies.

WORK RATE

The rate at which any production system can accomplish work is the product of the tool work rate, the number of tools which can be operated simultaneously on the workpiece, and the proportion of time the tools are accomplishing work. Schedule constraints usually require multiple craftsmen working in concert to achieve timely completion of ship subassemblies. Ship construction flexible automation systems are bound by the same schedule constraints. That means that these systems must achieve higher tool work rates, apply multiple tools to the workpiece, and increase the proportion of time that the tools are engaged with the workpiece. Each of these options affects the system technical feasibility.

FLEXIBILITY

Modern practice organizes the great variety of ship construction workpieces into process lanes. The work is partitioned such that the production problems encountered become generic to a given process lane and the total work content is relatively uniform between units in the lane. Process lanes, by definition, exhibit many of the properties of factory assembly operations subject to rapid product variation. These properties become evident in considering panel construction, generation of parts from structural shapes and the assembly of marine closures. In each case, time and labor required to handle and. position parts or stock, to index the automated production system to the workpiece, and to generate and load the program become very important relative to the total costs to product the workpiece. Automatic program generation from the engineering database is almost mandatory. Scott and Husband [2] have developed a principle of fixity relating the

costs of fixed and flexible portions of an automated assembly system to the time permitted to set up the system for a particular product and the total system for a particular product and the total system time allocated to that product. The proportionality constant has not been calibrated for ship construction automation projects. The shape of the curve is instructive as an indicator of proper balance in the design of a ship construction automated system. The indication heavily favors investment in flexibility.

LOW AGGREGATE COMPLEXITY

Low aggregate complexity will not independently establish the feasibility of a flexible automation system. Overly complex*systems are more difficult to integrate and to maintain than less complex systems. The higher the system complexity, the more likely that the performance of one or more features will constrain overall system performance to something less than the design goals. Low aggregate system complexity is an indicator of the probable success of otherwise technically feasible systems. This criterion tends to form truly simple systems. It also favors systems which directly resolve more complex production problems.

Lights, bells, and whistles impress, but like the grade school adage, "Pretty is as pretty does". Operators need direct access to minimal sets of functional commands specifically related to causing accomplishment of the task to be done. This will permit the operator and other personnel working in concert with the system to function as craftsmen. Adequate provision for the safety of these people is paramount.

DIVISION OF LABOR

Machines are capable of greater speed and consistence, and better able to withstand process related stresses (force and vibration, noise, heat, smoke and fumes) than are personnel. Craftsmen are better able to deal with unstructured work situations, and can apply many more degrees of mechanical freedom. Far greater dexterity of ship construction

operations dictates manual operators exercise at least supervisory control of flexible automation systems. Ergonomic concerns are well served by evaluating how effectively proposed ship construction flexible automation projects achieve safe and suitable division of labor between man and machine.

UTILITY

Flexible automation systems working in factory environments are often able to operate with a fair degree of autonomy and isolation from the rest of the plant. Parts are presented to the system in a fixed location and orientation. The system accomplishes its function and the part is returned to a fixed location. This is all very fine and well, but in ship construction, efficient accomplishment of a work function is not enough. What is necessary is system utility. Utility means that the system accomplishes a complete task, preferably completing a ship subproduct. This function must be accomplished in such a way as to complement and not add work to adjacent operations. The system must be capable of adapting to the handling practices, parts locating capabilities, and dimensional tolerances of upstream manual ship construction practices. When the system has completed its work, the subproduct made should be ready for the next stage of assembly, dimensionally compatible with other portions of the ship and not requiring adjustment or dimensional survey. The productivity of the system must be capable of achieving balance with adjacent operations. ‘This criterion favors systems which function to combine or subsume multiple operations as a consequence of mechanization. Systems which accomplish larger work contents are favored as are those systems which require the least accommodation in adjacent operations.

PROFITABILITY

As in all things related to business, ship construction flexible automation projects must be evaluated on the basis of potential profitability. This follows from the first axiom of business which establishes that the purpose of a business is to maximize the wealth of the

owners [3]. The operative word is “wealth”, and not cash. Wealth has at least two components, cash or value in hand, and the power ‘to generate even more wealth. It is unwise to neglect either component. Excessive capital investment risks a market shift and a potential shortage of operating funds.

American business is learning again that programs to maximize only cash are hoarding [4]. It is something like a farmer storing his entire crop for many years in anticipation of higher prices. He has no seed for a new crop. Productive farmers pass him by. Sooner or later, the stored crop will not germinate. We need a balance of cash management for today and investment in order to be in the ship construction business tomorrow.

This leads to the second axiom of business, which identifies that because of tomorrow’s risk, value in hand has more worth than the same value tomorrow. Be prepared to show potential profitability of proposed flexible automation projects on the basis of discounted value. Make sure your accountant not only considers cash flow, but also the value of improved competitive position provided by flexible automation systems.

For a flexible automation system, profitability means accomplishing a ship construction task at a significantly lower cost than the actual cost present methods and the cost of capitalizing the system. Profitability will favor feasible systems and accomplish a high work content. It will also favor replacement operations which have under present methods a large necessary no value added work content which can be subsumed as a consequence of mechanization. This includes such things as reassuring marking, layup, positioning and orientation. It also includes lofting, template making and maintenance, and detail work planning. The profitability criterion will favor projects with high utilization factors.

CONCLUSION

Ship construction is a unique industry. Traditional criteria for evaluating flexible automation projects are not always appropriate. New criteria are needed. These criteria

are, however, complex and comprised of several components. Flexible automation projects exhibiting high levels of feasibility, safety, utility, and potential profitability will be successful when they are implemented in ship construction.

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PANEL SP-023-l

SURFACE PREPARATION AND PAINTING

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OVERCOATING OF INORGANIC ZINC PRIMERS FOR UNDERWATER SERVICE

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ABSTRACT

A study sponsored by **MARAD** under the National Shipbuilding Research Program was undertaken to determine whether overcoating of inorganic zinc primers for underwater service will result in accelerated blistering or disbondment of the topcoat. The study included 5 inorganic zinc primers -- 2 U.S.-manufactured preconstruction type, 1 Japanese preconstruction type, and 2 full-coat type. Two different weathering periods were tested -- **7** days **and 60** days. Three different topcoats were evaluated, including the Navy MIL-P-24441 system and two commercial epoxy coating systems. Coated test panels were subjected to three different tests to rank susceptibility to blistering: (1) quiescent seawater immersion at a potential of -1.0 volt vs. SCE, (2) quiescent seawater immersion at 25 psi, 150°F, and (3) continuous seawater flow at 18 knots. Interim test results suggest that, for underwater service, overcoating of certain inorganic zinc primers may result in premature blistering or disbondment of the topcoat.

SUMMARY

Based on limited test results obtained to-date, it appears that topcoats tend to blister when applied over inorganic zinc primers versus white-metal steel in underwater service. Also, the results suggest that topcoat blistering/disbondment is more probable on full-coat vs. preconstruction primers. Finally, the

results indicate that inorganic zinc primed test panels weathered for a 60-day period are more prone to topcoat blistering than those weathered for a 7-day period.

INTRODUCTION

A study administered by Avondale Shipyards under MARAD's National Shipbuilding Research Program is in progress, the objectives of which are as follows:

- To determine whether it is necessary, for underwater marine service, to remove inorganic zinc shop primers by abrasive blasting prior to the application of a final coating.
- To determine the surface preparation requirements when overcoating inorganic zinc shop-primed steel for underwater service.
- To determine whether high performance marine coatings are compatible with inorganic zinc primers in underwater service.
- To determine to what extent cathodic protection will affect the performance of coatings applied over inorganic zinc primers.

The following paper summarizes results-to-date of the study.

BACKGROUND

Numerous investigators have discussed blistering problems associated with overcoating inorganic zinc primers (1), (2), (3),

(4). The ability to overcoat inorganic zinc primers in underwater service without incurring subsequent blistering is the primary issue and basis for the subject study. It has been reported that Japanese shipyards are overcoating inorganic zinc preconstruction primers on underwater surfaces without apparent problems. Because of the above-described blistering concerns,the predominant practice in the U.S. is to blast off the preconstruction primer prior to applying the hull coating.*

It has been suggested that the reason the Japanese are able to overcoat without problems is that they 'are using preconstruction primers with very low zinc levels, that are less reactive, and have less of a tendency to liberate hydrogen gas when contacted by water. The lower zinc levels do not provide comparable corrosion protection to those traditionally used in U.S. yards, however, the turnaround time for steel plate fabrication in the Japanese yards is supposedly lower than in U.S. yards (2-3 months vs. 6-9 months), and thus it is believed the additional corrosion protection is unnecessary.

Topcoats with a lower zinc level in the dry film will also tend to be less porous (if the size of the individual zinc particles is equal). Such primers would be less likely to cause the problems associated with zinc primer porosity.

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* The U.S. Navy does not permit overcoating of inorganic zinc primers for underwater service.

EXPERIMENTAL APPROACH

General Test Plan

The general test plan comprised the evaluation of three different epoxy topcoats over each of five inorganic zinc primers. Of primary interest is the effect of different weathering periods for the inorganic zinc primers on the performance of the topcoats. Prepared test panels have been exposed to three different test environments: (1) quiescent seawater immersion at a potential of -1.05 volt vs. SCE, (2) quiescent seawater immersion at 150°F, 25 psi, and (3) flowing seawater at 18 knots.

Coatings Selected For Testing

Table 1 provides a general description of each of the five inorganic zinc primers selected for testing. Table 2 provides a description of the topcoats included in the test program.

Test Panel Preparation

The inorganic zinc primers were applied to ASTM A-36 steel panels, white-metal blasted to obtain a surface profile between l-2 mils. The nominal panel dimensions were 6" x 12" x l/8" thick for quiescent immersion testing and 5 l/4" x 7 l/2" x l/2" thick for flow testing.

The inorganic zinc primers were applied by airless spray using an automated application system designed to provide close control of applied film thickness. The system utilized a fixed spray gun with apparatus for moving the test panel by the spray

gun nozzle at a controlled speed. After coating, the dry film thickness on all test panels was determined using an Elcometer magnetic thickness gauge. The average applied coating thickness of the respective inorganic zinc primers was as follows:

Primer #l - 1.0 mil

Primer #2 - 0.7 mil

Primer #3 - 0.8 mil

Primer #4 - 4.2 mils

Primer #5 - 2.1 mils

After application of the zinc primers, all test panels were weathered on the test fences at the Ocean City Research Corporation Sea Isle test site. This test site provides a natural marine atmosphere and is located approximately 300 feet from the ocean. One-half of the test panels were exposed for 7 days, the other half for a period of 60 days in order to evaluate the effect of different weathering times. After weathering, all test panels were lightly sanded with 600 grit silicon carbide paper to remove any zinc corrosion product (white rust).

After sanding, the test panels were topcoated with one of the three epoxy topcoats. The topcoat systems were applied in accordance with manufacturer's directions using hand-controlled airless spray equipment. After coating, all panels were inspected for "holidays" using a wet-sponge, 67.5 volt holiday detector. All holidays were suitably repaired. The panels were allowed to cure for10 days before being placed into **test.**

After topcoating, the dry film thickness of all panels was again determined using the same equipment as described previously. The average applied coating thickness of the respective topcoat systems was as follows:

Coating #1 - 9.6 mils (applied in 2 coats)
Coating #2 - 11.0 mils (applied in 2 coats)
Coating #3 - 9.2 mils (applied in 3 coats)

During application of the topcoats, some blistering problems were encountered. Depending on the particular primer over which the topcoat was being applied, small blisters or pinholes developed almost immediately after topcoating. This problem occurred even with the application, first, of a thin mist coat (0.25 to 0.5 mil) which was allowed to tack up before applying the full coat. The problem was most evident on zinc primers #4 and #5, the two full-coat'inorganic zincs included in the program. Little or no blistering was observed over the thinner preconstruction primers.

As an experimental benchmark, the respective topcoats were also applied to white-metal blasted steel test panels. No application problems were encountered on these test panels.

Duplicate test panels of each coating system were prepared for each of the seawater immersion exposure tests. For the flow test, single panels were prepared. The total number of test panels prepared for exposure testing was 165.

Performance Testing

Three different types of exposure tests are being conducted in the study to evaluate the performance of representative top-coats applied over different inorganic zinc primers. These tests include: (1) quiescent seawater immersion at a potential of -1.0 volt vs. SCE (2) quiescent seawater immersion at 25 psi, 150°F and (3) seawater flow at 18 knots.

Seawater Flow At 18 Knots. A single test panel (5 l/4" x 7 1/2" x 1/2" thick) for each weathering/primer/topcoat condition was exposed in the OCRC natural seawater flow channel for a period of 30 days at a velocityof 18 knots. Each panel received a 1" vertical scribe centered on each side.

The natural seawater flow channel is designed to permit velocity testing under flow conditions that are reasonably representative of the flow conditions that would exist over a major portion of a ship's hull -- fully developed parallel, turbulent, high Reynolds Number, seawater flow. The flow channel accommodates comparatively larger test panels, thus tending to minimize edge and/or boundary effects. The width of the channel cross section varies along the length permitting testing at different flow velocities simultaneously. Figure 1 shows the flow channel while Figure 2 shows the method by which test panels are typically mounted in the flow channel.

Seawater flow through the channel is accomplished using a double-suction centrifugal pump powered by a 100 HP motor. The flow rate exceeds 5,000 gpm and is measured using a factory-

calibrated 316 stainless steel orifice plate/differential pressure gauge set-up. The rate of seawater make-up into the channel can be adjusted to control seawater temperature to within 22.5 C and maintained sufficiently high to avoid stagnation or concentration effects.

Quiescent Seawater Immersion @ -1.0 volt. Duplicate test panels (6" x 12" x 1/8" thick) for each weathering/primer/topcoat condition are suspended in 100-gallon plastic tanks filled with fresh seawater. The seawater tanks are continually refreshed at a rate sufficient to effect a complete changeover 3 times a day. The seawater temperature is maintained at 70°F.

A lead wire was attached to each test panel facilitating electrical connection to a zinc anode. Electrical coupling to a zinc anode maintains the test panels at a potential of -1.0 volt versus a saturated calomel electrode. Prior to the start of test, each test panel received a 1/4" radial holiday directly in the center of one side. The planned test duration is 6 months.

Quiescent Seawater Immersion @ 25psi, 150°F. Duplicate test panels are also immersed in seawater maintained at 25 psi, 150°F. Each test panel has a 1" vertical scribe centered on one side. The panels are mounted in PVC racks. The racks are then inserted into a 12-inch diameter PVC pipe which serves as the test chamber. A pump provides seawater make-up while maintaining a positive pressure inside the pipe of 25 psi. The make-up flow is sufficient to effect a complete changeover once a day. The temperature is controlled at 150°F with two thermosensors im-

mersed in the test chamber which are coupled to a nichrome heating element wrapped around a titanium heat exchanger. The seawater is constantly circulated through the heat exchanger to maintain temperature. The planned test duration is **6** months.

Inspection/Evaluation Procedures

During the course of each of the three exposure tests, the test panels are periodically removed, visually inspected, and rated for blistering, disbondment, and/or other forms of deterioration. At the conclusion of each test, the total extent of coating disbondment is determined by making x-shaped cuts with a sharp knife through the coating and lifting all loose or disbonded coating with the point of a knife.

INTERIM RESULTS

Weathering Of Inorganic Zinc Primers Before Topcoating

Visual inspection of the inorganic zinc primed panels after the two different weathering exposures (7 days, 60 days) showed significant differences on only one primer (#1). For system #1, the panels exposed for 60 days exhibited extensive rust-through while those exposed for only 7 days showed no evidence of rust-through. This is shown in Figure 3. Of the three preconstruction primers, Primer #1 had the lowest zinc loading in the dry film.

For the other four inorganic zinc primers, there were only slight, visually detectable differences between the 7-day and 60-

day panels, with the 60-day panels exhibiting slightly more corrosion product (white rust).

Seawater Flow Tests

Table 3 summarizes the extent of topcoat disbondment per panel side after 30 days in test as well as pertinent observations over the course of the tests. As is evident from Table 3, some panels exhibited disbondment within 24 hours after the start of the test.

Table 4 is a condensed version of Table 3, and shows the total area of disbondment by inorganic zinc primer and by individual topcoat. Based on the 30-day results, topcoats applied over Primer #4 showed significantly more disbondment than the other systems. Primer #4 was a 2-component, full-coat system applied at an average thickness of 4.2 mils (the heaviest applied thickness included in the test program). The least amount of topcoat disbondment was observed on Primer #1 an alkyl silicate type preconstruction primer applied at an average DFT of 1 mil. It is noteworthy to point out that the manufacturer of Primer #1 does not recommend overcoating the primer on underwater surfaces.

Of special interest was the comparative topcoat performance over Primer #3 a Japanese preconstruction primer whose manufacturer suggests can be topcoated (without need of wash down or sandsweep) for underwater service. As is evident, significant disbondment occurred on two of the six test panels over 30 days. On both panels, some degree of disbondment was observed within 24 hours after start of the test.

Comparison of the disbondment results by topcoat shows that Topcoat #3, the standard Navy hull coating (MIL-P-24441, Type 1), exhibited the least amount of disbondment over 30 days. For this topcoat, disbondmentoccurred only on those panels primed with Primer #4.

For four out of five primers, the total area of topcoat disbondment was greater on the panels weathered for 60 days versus 7 days. However, additional data is required to establish that this observation is statistically significant with reasonable probability.

An interesting observation is the extensive rusting evident in the areas where the topcoats disbonded. This observation suggests that the zinc primers tend to sacrifice rapidly once exposed to flowing seawater. Furthermore, it suggests that, at holidays, topcoats will be prone to underfilm lifting and disbondment as the zinc coating rapidly dissolves.

Quiescent Seawater Immersion @-1.0 Volt

Through the first 6 weeks of a planned 6-month test, there is no detectable topcoat disbondment on any of the test panels.

Quiescent Seawater Immersion @25 psi, 150°F

Table 5 summarizes the results of weekly inspections made during the first month of testing. Figures 4 and 5 show typical deterioration observed over the first **30** days in test. As is evident from Table 5, blistering/disbondment has been detected on 26 of the 60 panels (43%) in test. Of the 26 panels exhibiting

blistering/disbondment, 18 of the panels were weathered for a 60-day period while the remaining 8 were weathered for a 7-day period. Six of the eight 7-day weathering period panels that exhibited blistering were coated with Primer #4. The results of the flow test discussed previously suggested that there may be a greater tendency for topcoat blistering with Primer #4 than the other primers being tested. Based on the 150°F immersion test results to-date for those panels weathered for 7 days, there also appears to be a greater tendency for blistering of topcoats applied over Primer #4. For the panels weathered for 60 days, blistering has been detected on all topcoats over all primers with one exception (Topcoat #2/Primer #2). No blistering has been detected on the control panels (topcoats applied to white-metal steel).

Comparison of the results-to-date by weathering period suggests that those panels weathered for 60 days are more prone to cause topcoat blistering.. Also, given the lack of any visible blistering on the control panels, the results suggest in general that there is a greater tendency for topcoat blistering over inorganic zinc primers than white-metal steel. The results should be qualified, however, in that the environment of the subject tests is not exactly representative of typical service conditions. It has not been demonstrated that the results of these higher temperature tests will necessarily correlate with exposure under lower temperature conditions. There does appear to be good correlation between these tests and the seawater flow tests.

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Table 1 - General Description Of Inorganic Zinc Primers Selected For Testing

Coating No.	Description
1	U.S. manufactured, single component, alkyl silicate type preconstruction primer, 35% zinc in the dry film, recommended dry film thickness = 0.6 - 1.0 mil.
2	U.S. manufactured, 2-component, modified zinc silicate preconstruction primer, 86% zinc in the dry film, recommended dry film thickness = 0.6 - 1.0 mil.
3	Japanese manufactured, 2-component preconstruction primer, 50% zinc in the dry film, recommended dry film thickness = 0.5 - 0.7 mil.
4	U.S. manufactured, 2-component, full-coat primer, 56% volume solids, recommended dry film thickness = 3.0 mils.
5	U.S. manufactured, 2-component, full-coat primer, 63% volume solids, recommended dry film thickness = 2.0 mils.

Table 2 - General Description Of Topcoats Selected For Testing

Coating No.	Description
1	Two-component, polyamide-cured high-build coal-tar epoxy, 67% volume solids, recommended application thickness = 5 mils (DF)/coat.
2	Two-component, polyamide-cured epoxy, 56% volume solids, recommended application thickness = 5 mils (DF)/coat. Meets MIL-P-23236, Type 1, Class 1.
3	Two-component, polyamide-cured epoxy, recommended application thickness = 2-3 mils (DF)/coat. Standard U.S. Navy underwater hull coating meeting MIL-P-24441, Type 1.

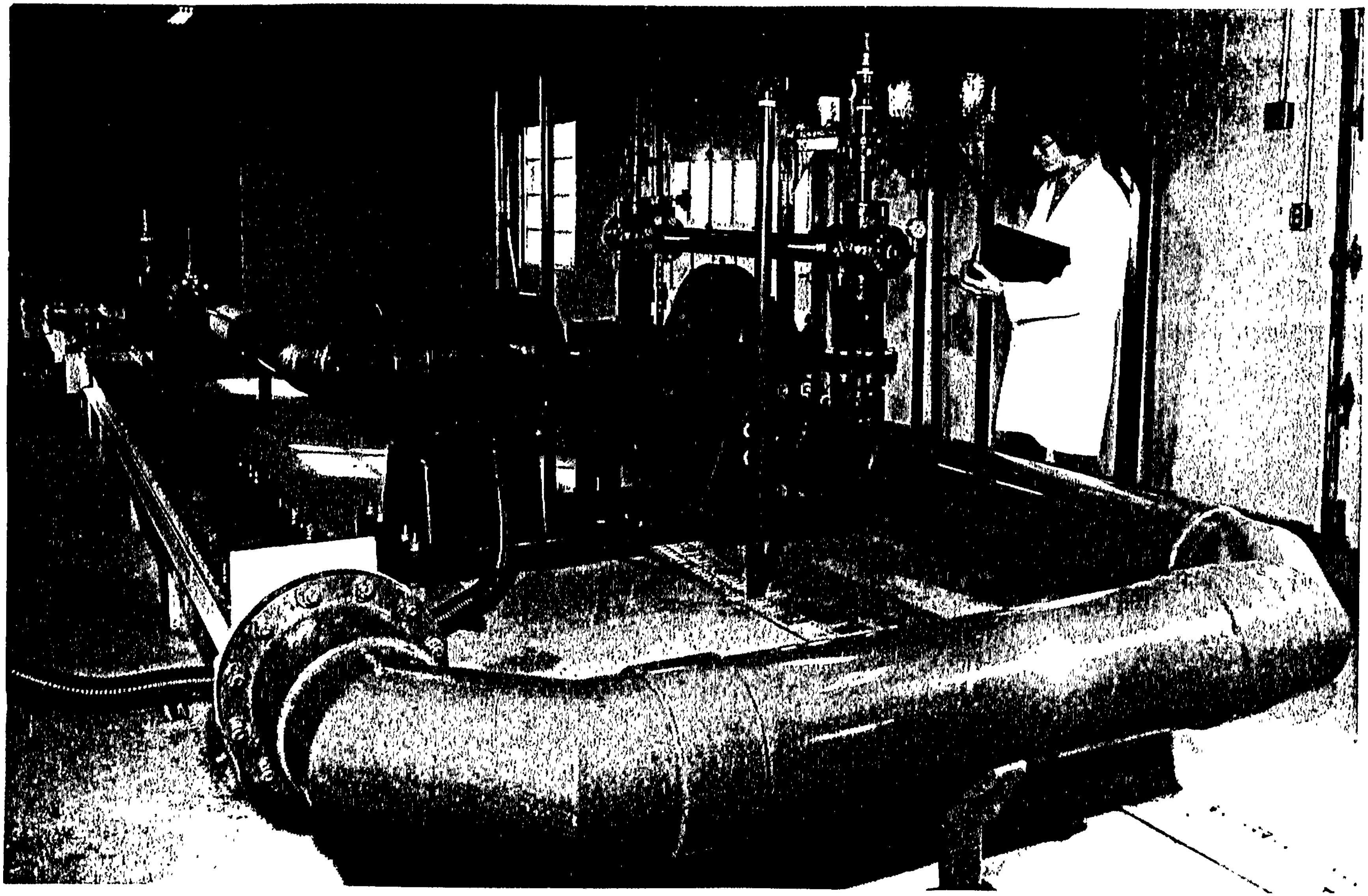

Figure 1 - Seawater Flow Channel

1 STEEL CHANNEL
2 T-BOLT
3 TEST PANEL
4 ACRYLIC PLATE
5 STEEL PLATE
6 WELD
7 ELECTRICAL LEAD CONNECTION

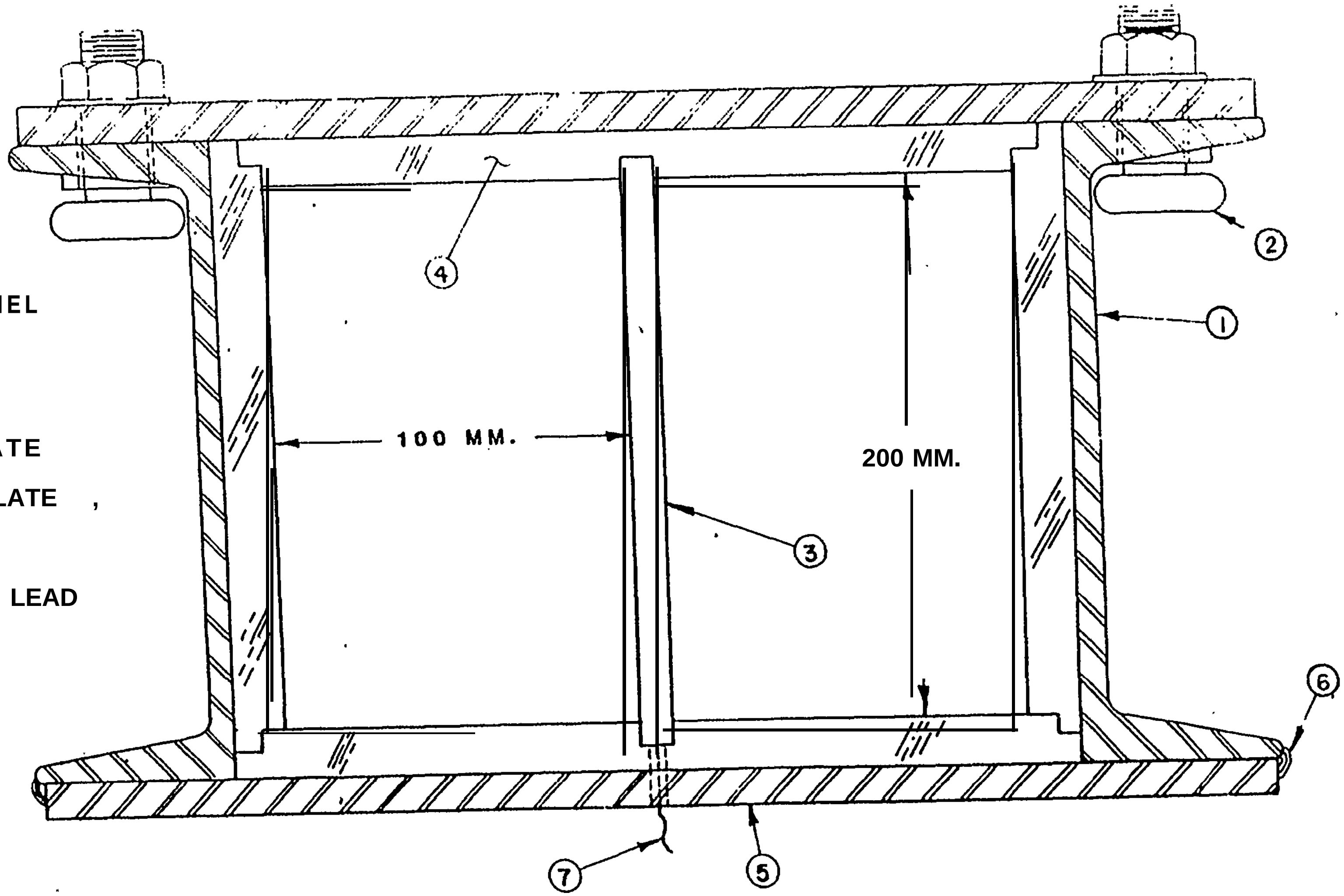

Figure 2 - General Arrangement Of Test Panel In Seawater Flow Channel

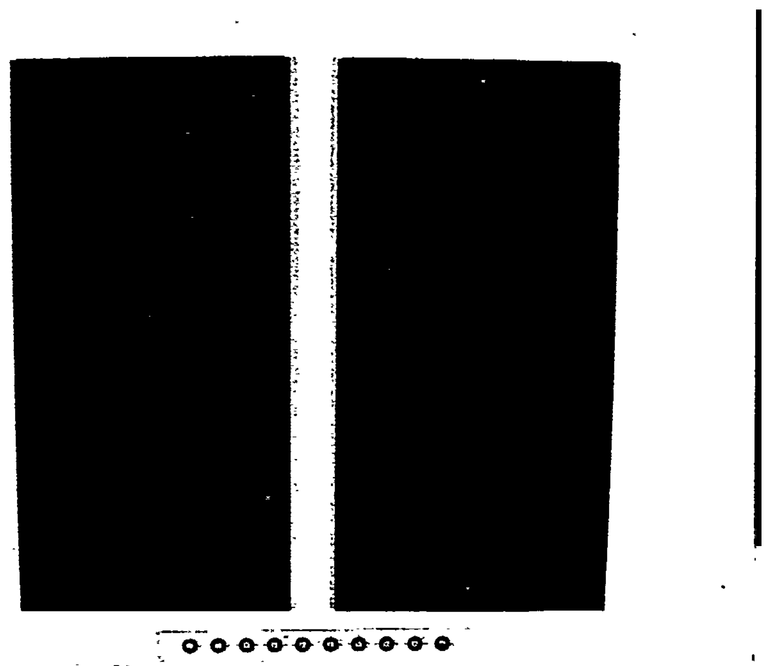

Figure 3 - Primer #1 After 7 (right) and 60 Day (left) Weathering Periods

Table 3 - Summary Of 30-Day Seawater Flow Tests

Inorganic Zinc Primer	Topcoat	Weathering Period	Area of Disbondment, in2 Side #1	Side #2	Total	Remarks
# 1	# 1	7-day	0.00	0.00	0.00	
1	# 2	7-day	0.17	0.42	0.59	
# 1	# 3	‘I-day	0.00	0.00	0.00	
# 1	# 1	60-day	0.10	0.06	0.16	
# 1	# 2	60-day	0.10	0.31	0.41	
# 1	# 3	60-day	0.10	0.12	0.22	
# 2	# 1	7-day	2.00	5.50	7.50	Disbondment detected on side #2 @ 5 days; Disbondment detected on side #1 @ 15 days
#2	# 2	7-day	0.02	0.00	0.02	
# 2	# 3	7-day	0.22	0.18	0.40	
# 2	# 1	60-day	0.00	0.0	0.00	
# 2	#2	60-day	0.09	8.50	8.59	Disbondment detected on side #2 @ 4 hours
#2	# 3	60-day	0.04	0.08	0.12	
# 3	# 1	7-day	0.07	0.02	0.09	
# 3	# 2	7-day	0.00	21.0	21.0	Disbondment detected on side #2 @ 4 hours
# 3	# 3	7-day	0.04	0.04	0.08	
I 3	# 1	60-day	0.00	5.00	5.00	Disbondment detected on side #2 @ 24 hours
# 3	# 2	60-day	0.05	0.07	0.12	
#3	# 3	60-day	0.06	0.09	0.15	

Table 3 (Cont'd)

Inorganic Zinc Primer	Topcoat	Weathering Period	Area of Disbondment, in2 Side #1	Side #2	Total	Remarks
# 4	#1	'I-day	8.00	0.00	8.00	Disbondment detected on side #1 @ 12 days
# 4	# 2	'I-day	12.00	0.13	12.13	Disbondment detected on side #1 @ 4 hours
# 4	# 3	'I-day	2.00	2.30	4.30	Disbondment detected on sides #1 and #2 @ 16 days
# 4	#1	60-day	14.00	10.00	24.00	Disbondment detected on sides #1 and #2 @ 16 days
# 4	. # 2	60-day	0.28	0.00	0.28	
# 4	# 3	60-day	0.16	13.50	13.66	Disbondment detected on side #2 @ 24 hours
5	#1	7-day	0.00	0.00	0.00	
#5	#2	7-day	0.08	0.08	0.16	
# 5	# 3	7-day	0.00	0.00	0.00	
# 5	# 1	60-day	0.06	0.00	0.06	
# 5	#2	60-day	20.00	0.00	20.00	Disbondment detected on side #1 @ 4'hours
#5	# 3	60-day	0.00	0.11	0.11	
Control	#1		0.05	0.00	0.05	
Control	# 2		6.30	0.16	6.46	Disbondment detected on side #1 @ 16 days
Control	# 3		0.11	0.05	0.16	

Table 4 - Total Area Of Disbondment After 30 Day Seawater Flow Tests

Inorganic Zinc Primer	Weathering Period	Area of Disbondment, in2 Topcoat #1	Topcoat #2	Topcoat #3	Total
#1	7-day	0.00	0.59	0.00	0.59
#1	60-day	0.16	0.41	0.22	0.79
#2	7-day	7.50	0.02	0.40	7.92
#2	60-day	0.00	0.59	0.12	8.71
#3	7-day	0.09	21.0	0.08	21.17
#3	60-day	5.00	0.12	0.15	5.27
#4	7-day	8.00	12.13	4.30	24.43
#4	60-day	24.00	0.28	13.66	37.94
#5	7-day	0.00	0.16	0.00	0.16
#5	60-day	0.06	20.00	0.11	20.17
Control	-	0.05	6.46	0.16	6.67
	TOTAL	44.86	69.76	19.20	

Table 5 - Summary Of Inspection Results After 30-Days In Test; Quiescent Seawater Immersion @ 25 psi, *150°F*

Inorganic Zinc Primer	Topcoat	Weathering Period	Observations
#1	#1	7-day	No evident deterioration
# 1	#2	7-day	No evident deterioration
# 1	#3	7-day	No evident deterioration
#1	# 1	60-day	Slight blistering on one side of a duplicate panel at 29-day inspection
#1	# 2	60-day	Blistering on one side of a duplicate panel at 14-day inspection
# 1	# 3	60-day	One panel blistered on both sides at 7-day inspection
# 2	# 1	7-day	No evident deterioration
# 2	#2	7-day	No evident deterioration
# 2	#3	'I-day	Slight blistering on one side of a duplicate panel at 29-day inspection
# 2		60-day	Slight blistering on one side of a duplicate panel at 2l-day inspection
# 2	#2	60-day	No evident deterioration
# 2	# 3	60-day	Slight blistering on one side of a duplicate panel at 21-day inspection
# 3	# 1	7-day	No evident deterioration
# 3	#2	'I-day	Large blisters on one side of a duplicate panel at 7-day inspection
# 3	# 3	7-day	No evident deterioration
# 3	# 1	60-day	Both panels progressively blistering, first detected at 7-day inspection
# 3	# 2	60-day	Heavy blistering of a duplicate panel at 7-day inspection
# 3	# 3	60-day	Medium blistering on one side of a duplicate panel at 2l-day inspection

Table 5 (Cont'd)

Inorganic Zinc Primer	Topcoat	Weathering Period	Observations
#4	# 1	7-day	One panel blistered at 7-day inspection progressing to 20% disbondment at 21-day inspection, duplicate panel blistered at 29-day inspection
#4	# 2	7-day	Both panels heavily blistered on both sides at 7-day inspection
#4	#3	‘I-day	One panel disbonded 50 and 90% at 7-day inspection, duplicate panel disbonded 75% one side at 7-day inspection
#4	# 1	60-day	Both panels progressively blistering, first detected at ‘I-day inspection
#4	# 2	60-day	Both panels heavily blistered on both sides @ 21-day inspection
#4	# 3	60-day	One panel 5% disbonded at 7-day inspection
# 5	# 1	‘I-day	No evident deterioration
#5	# 2	‘I-day	No evident deterioration
# 5	# 3	‘I-day	No evident deterioration
#5	# 1	60-day	Blistering on one side of duplicate panel @ 21-day inspection
#5	# 2	60-day	Blistering on one side of duplicate panel @ 7-day inspection
#5	# 3	60-day	Blistering on one side of duplicate panel @ 7-day inspection
Control	# 1		No evident deterioration
Control	# 2		No evident deterioration
Control	# 3		No evident deterioration

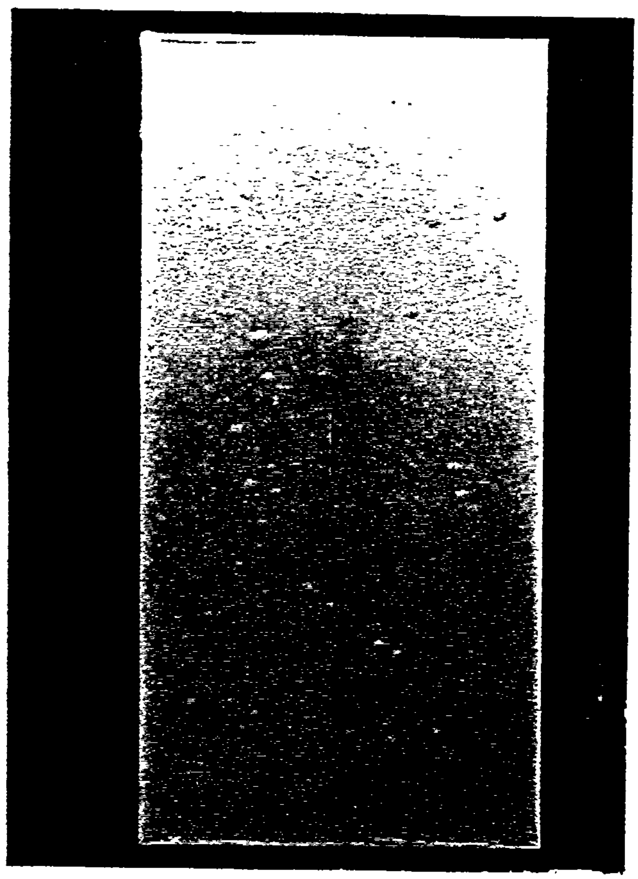

Figure 4 - Topcoat Blistering After 7 Days Exposure To Seawater @ 150°F, 25 psi; Primer #4/Topcoat #2

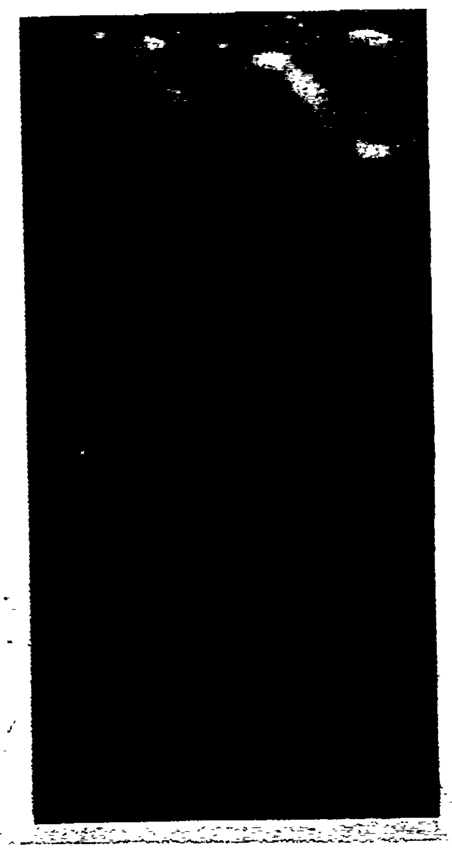

Figure 5 - Topcoat Blistering And Disbondment After 7 Days Exposure To Seawater @ 150°F, 25 psi; Primer #4/Topcoat #3.

NATIONAL SHIPBUILDING RESEARCH PROGRAM (NSRP)

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EVALUATION OF WET BLASTING FOR SHIP APPLICATION

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ABSTRACT

This paper presents the results of a field investigation of equipment and technology for wet abrasive blasting as a technique for preparation of structural steel for painting. Ten different commercially available wet blasting units were selected for field evaluation. The units selected included the following generic types: air abrasive wet blasting (addition of water at the nozzle to conventional dry blasting equipment); air/water/abrasive slurry blasting (mixing of water with the abrasive at a control unit upstream of the nozzle); pressurized water abrasive blasting (abrasive added to high or low pressure water jetting stream); and ultra high pressure water jetting (2Q,OOO psi or greater). These evaluations were conducted on steel surfaces, typically encountered in shipyards and industrial environments, including rusted and pitted steel, milscale steel, and painted steel. The investigation considered factors such as the cleaning rates, abrasive and water consumption, operator thrust, portability, safety procedures required, use of inhibitors, and overall practicability and reliability. The paper discusses each of these factors and provides a tabulation of advantages and disadvantages for each unit observed.

BACKGROUND

IT IS UNIVERSALLY ACKNOWLEDGED that dry abrasive blasting is the most efficient and economical technique for cleaning structural steel for painting in industrial applications. The abrasive blasting unit delivers to the surface a high velocity stream of hard, angular. abrasive, which has the ability to rapidly remove for improved adhesion. The equipment and techniques for dry blasting have become standardized to a high degree and provide a high degree of reliability.

Dry blasting has been restricted in recent years because of health hazards from silica dust inhalation: air quality concerns with visibility, suspended particulates, and fugitive or nuisance dust; and dust contamination of machinery or equipment. There has also been concern about the disposition of the spent abrasive, which may contain lead compounds or other toxic materials from the paint film.

Alternatives to sand .blasting include silica-free low-dusting abrasives, high pressure'water blasting, wet sandblasting, power tool cleaning, and chemical cleaning. Alternative abrasives such as mineral slags often eliminate the *silica* hazard, but these abrasives may be more expensive or difficult' to obtain than sand and have recently been under attack 'for some trace concentrations of *toxic* heavy metals. High pressure water blasting and hand and power tool cleaning are suitable for removing loose rust and paint, but cannot remove tight mill scale, tight rust, and paint. Other new techniques have been described but have not yet proven practical for large scale production cleaning of steel.

Wet abrasive blasting offers the potential to reduce or eliminate many of the problems associated with dry blasting and at the same time offers relatively high production rates and cleaning efficiency.

There are several generic types of wet blasting equipment with large variabilities in operating parameters, reliability, cleaning rates and effectiveness, cost, safety, and user satisfaction. This article describes the results of field evaluations of several different types and manufacturers of equipment for wet blasting.

The emphasis of this *study* was the observation and evaluation of field demonstrations rather than obtaining data literature values or second-hand accounts. From a review of trade and technical literature and public requests for information, ten different wet blast units were selected for evaluation. These evaluations were conducted on steel surfaces typically encountered in marine, highway, and water works maintenance, such as rusted and pitted steel, mill scale covered steel, and painted steel. For each demonstration, the representative structures were cleaned using wet blast techniques and *dry* blast cleaning controls, with careful documentation of cleaning rates, cleanliness, and other factors required for the evaluation.

DESCRIPTION OF UNITS AND TECHNOLOGY

Wet blast units can be categorized into four major types as shown in Table 1. Two of these involve air abrasive blasting with water addition. The *others* are pressurized water blasting with and without abrasives. The basic principles and variations of these types of wet blasting *will* be *reviewed* briefly. The discussion will also review the most important parameters and features and components of the various types of systems investigated.

AIR ABRASIVE WET BLASTING The air abrasive wet blasting units vary with respect to the method and location of water addition, the type of control

TABLE 1
CLASSIFICATION OF WET BLASTING UNITS

Air Abrasive Wet Blasting
Air/Water/Abrasive Slurry Blasting
Pressurized Water Abrasive Blasting
High Pressure Water (6,000-15,000 psi
Low Pressure Water (2,000-4,000 psi)
Ultra High Pressure Water Jetting- (20,000-50,000 psi)

system, the device for adding and monitoring inhibitor, and the design of the nozzle and the overall system. Water can be added at the source of the abrasive, just before the sand enters the nozzle, or downstream of the nozzle. One of the earliest methods was the water envelopment process or "water curtain method," which projects a cone of water around the stream of air and abrasive as it leaves the nozzle. A simple water ring adapter fits around the blasting hose nozzle. This technique is reported to reduce the airborne dust by SO-75%. It has a minimal effect on the cleaning rate because the water does not mix with the abrasive. It does make the unit slightly more unwieldy and could affect cleaning rate in that manner.

The water stream could also be sprayed into the abrasive stream beyond the nozzle. This gives a greater degree of dust control than the water envelope method because the abrasive is wet before it reaches the surface.

In the second type of air abrasive wet blasting, the water is added to the abrasive just before it reaches the nozzle. In one version, a nozzle adapter is mounted between the nozzle holder and nozzle. Pressurized water from an air-operated pump is controlled with a needle valve. The water pressure is normally on the order of 300-800 psi. For many of these units, the water and sand can be operated independently. Thus, for example, by closing the needle valve, one can dry sandblast in areas where wet blasting may not be needed. Also, by releasing the nozzle handle, one can use the low pressure water to wash off the sand from the surface.

These units may be designed as a retro-fit for existing abrasive blasting units or complete unit, including abrasive blast machine, air powered pump, and a mixing tank. These types of units are extremely effective in reducing the amount of dust.

AIR/WATER/ABRASIVE SLURRY BLASTING Another technique is addition of water to the abrasive stream at the control unit upstream of the nozzle. In these systems, the mixture of air, water, and sand is propelled through the hose to the nozzle without any additional coupling at the nozzle. In several of these units, the air, water, and *sand* can be independently-controlled by the operator, either by microswitches at his control, or remotely by another operator, who may be in audio contact with the blaster. As with the previous types of systems, these units allow the operator to rinse off the wet sand from the surface with pure water, often containing an inhibitor. Certain units can be used to feather back paint by reducing the air pressure, resulting in a less erosive slurry stream. Because the sand is intimately mixed with the water, these units are also very effective in reducing the amount of dust.

HIGH PRESSURE WATER BLASTING High pressure water blasting is a technique which produces a high velocity stream of water by passing a flow of pressurized water through a specially designed small orifice nozzle. This jet has some erosive force and has been utilized for removing paints and corrosion products from structural steel. The principal focus of this study is on water blasting with abrasives rather than on pure water blasting. However, for comparison purposes, observations were made of several high pressure units operating without abrasives. In addition, a unit that was *designed* to be operated without sand because of the extremely high pressures attained was observed.

The major components of a water blasting unit are as follows:

:: Positive displacement pump and appropriate power unit
* High pressure hydraulic delivery hose
# High pressure nozzle
# Control valve system

Other components include water filter, pressure gauge, **flow** meter, inhibitor, and metering and monitoring attachments.

High pressure water blasting without sand has not shown the capability of removing tight rust or intact mill scale from steel except at exceedingly slow rates or at ultra high pressures (greater than 3,000 psi). In addition it cannot produce a profile (surface roughening) of the steel itself. In order to introduce additional erosive force into water blasting, abrasives must be incorporated into the water jet.

PRESSURIZED WATER ABRASIVE BLASTING High pressure units use water pressures from 6,000-20,000 psi. The

flow rates are normally five to fifteen gallons of water per minute. These units require a different type of nozzle than that used for straight high pressure water jetting. The nozzle orifice must be large enough (typically 3/8") to permit the abrasives to pass through.

Also observed were several units which operated at substantially lower pressures and rates than those given above. Water blasters with pressures of 3,000-4,000 psi would be expected to provide much greater ease of handling and safety than the high pressure units. A few of these were simply high pressure units operated at reduced pressures. Others were designed for use at lower pressures.

OPERATOR BACK THRUST An important consideration is the amount of thrust that the operator must withstand in using a high pressure water blaster; thrust depends on the pressure, flow rate, and the nozzle orifice. Table 2 shows typical thrusts for several pressures and flow rates. It is noted that an operator thrust of greater than about 35-40 pounds can become very fatiguing after a relatively short period of time. Thrusts above 50 pounds cannot be controlled manually.

TABLE 2
OPERATOR BACK THRUST WITH WATER JET

Pressure (psi)	Flow Rate (gpm)	Thrust (lbs)
20,000	10	74
20,000		
10,000	10	53
10,000	6	
5,000	8	30
5,000.		
3,000	4	14

WATER-ABBRASIVE NOZZLES There are several nozzle designs available which introduce the abrasive into the water stream. Most of these rely on suction by the water stream to pull the abrasives into the nozzle.

In a typical design for introducing abrasives into the water stream, water enters the nozzle at a 90 degree angle through tiny orifice inserts. A recently patented alternate design is claimed to make it possible for the water to maintain the maximum velocity, minimize the loss of energy, and deliver more abrasive at higher impact.

A discussion of the relative merits of these nozzles is beyond the scope of this investigation. However, it was noted that there were considerable differences in the cleaning rates of several of the units tested, which could be attributable to the design parameters.

Another important parameter in water blasting, both with and without abrasive, is the standoff distance. At a small standoff (2-3 inches), the force of the jet on the surface is greatest, resulting in the highest degree of erosion. However, this also results in a smaller path width, and a lower overall cleaning rate.

INHIBITORS - Because of the tendency of wet steel to corrode rapidly (flash rust), inhibiting chemicals are often applied to the freshly blasted steel surface. The inhibitors are usually water soluble chemicals which prevent corrosion by passivating the steel surface (slow down corrosion by increasing the polarization).

Many commercial inhibitors use a combination of nitrite and phosphate. The use of chromate type inhibitors has greatly diminished because of the problems of chromate disposal.

There are as yet no standard or prescribed concentrations the nitrite and phosphate inhibitors in water or wet blasting. Typical values recommended by equipment manufacturers range from lOO-3,000 parts per million (ppm). There is little data relating the quantity of inhibitor needed per area to the time of protection afforded in environments of varying degrees of severity. There is also little data comparing the merits of the different inhibitors. In several of the demonstrations, the inhibitor aid prevent the flash rusting which was observed to occur in the absence of the inhibitor.

Another important criterion of the inhibitor is its effect on the performance of the paint applied over it. The inhibitors are water soluble species which tend to form crystalline materials upon evaporation of the water. Thus, osmotic blistering may result from the soluble salt on the surface. There is as yet little substantiated data to show what, if any, effect these inhibitors have on paint performance.

FIELD DEMONSTRATIONS

A total of ten different wet blast units was observed in field demonstrations. At several of these demonstrations, wet blast units were compared directly with dry blast units on equivalent surfaces. These data were considered most reliable. Data were also obtained from other field demonstrations in which only small surface areas were cleaned, or in which

the dry blast control was inadequate or nonexistent. Data from these latter demonstrations and from evaluations by other users or manufacturers were given less weight in assessing the relative merits of the various wet blast units.

Two of the major demonstrations included direct comparisons of high-pressure water sandblasting, air abrasive wet blasting, and dry blasting. In one demonstration, conducted at a painting contractor's yard facility, areas of approximately twelve square feet were cleaned to near-white metal; the original surfaces included plates with slightly rusting inorganic zinc-rich coating, rusted and pitted surfaces, and heavy layers of paint. The data showed that the two air-abrasive wet blast units and the dry sand- units had fairly comparable cleaning rates while pressure sandblaster was considerably slower. The water ring unit gave higher cleaning rates than the dry sand for the thick paint film.

Another demonstration was held at a distributor's yard. The three units were evaluated on flat steel containing mill scale and moderate rust, and on a heavily rusted steel beam. In this test, the air abrasive wet blaster cleaned at a slightly higher rate than the dry blast. Again, the high pressure water/sand blast was considerably slower. Sand consumption rates were also higher.

An air/water/sand unit was compared to dry sand blasting at a yard facility. The substrates were two grades of rust steel plate and some structural pieces. In these, the dry sand cleaning rate was 20-40% faster. In this evaluation, the time for washing the wet sand from the surface was included in the rate. The dry sandblasted surfaces were slightly better cleaned than the wet blasted surfaces.

Another air/water/sand unit was compared to dry blasting on a highway bridge. In this case the dry abrasives (both sand and coal slag) were several times more efficient than the air/water/sand unit. The lower cleaning rate obtained with the air/water/sand unit can be partly attributed to the operator inexperience and some variability in the surface condition of the bridge. Even making these allowances, however, air/water/sand was much slower for this type of cleaning than the dry blast units.

DISCUSSION OF FINDINGS

In selecting a surface preparation unit or evaluating such units, there,are several factors that must be considered. These include the following: cleaning rates, cleaning effectiveness, equipment reliability, safety, portability and versatility of equipment, and cost.

CLEANING RATES Overall. the cleaning rates with the air abrasive wet blasting were considerably higher than those using high pressure water. The former were .approximately in the range of 80-90% the rates of dry blasting. The cleaning rates with high pressure water abrasive blasting were about 30-508 that of dry blasting, but were not as well documented as the air-driven systems. The cleaning rate is increased at higher pressures or flow rates, but these also increase the thrust and the difficulty of controlling. In most cases, the cleanup rate and.expense are expected to be higher for the wet cleaning methods than for dry blasting.

Cleaning rates also depend on the skill of the operator. The high pressure water/sandblaster, and to a lesser degree, the air abrasive wet blasting reduce visibility. This often decreases cleaning rates because the operator cannot judge when he has sufficiently cleaned the surface and may repeat or miss some areas. In addition, for the high pressure abrasive blaster, the standoff distance and the angle of blasting affect cleaning rates. They will vary with the velocity of the jet (water pressure), nature of substrate, and the type of cleaning (e.g., removing of topcoat or cleaning to bare metal). The slurry blasting and the air abrasive wet blasting cleaning rates, as with any air blasting, depend on the air pressure.

Several of the lower pressure water abrasive blasting units gave cleaning rates that would be acceptable for many small to medium sized jobs. This would be particularly true for cleaning intricate structures or for maintenance crews. The rates for these units are estimated at 15-258 that of dry blasting.

CLEANING EFFECTIVENESS The major factors in determining effectiveness are:

Visual Cleanliness (removal of rust, mill scale, paint and dirt)
Chemical Cleanliness (removal of oil film and soluble salts such as chlorides and sulfate)
#: Surface Profile

Each of the types of wet blast units was capable of producing near-white metal. However, in most of the observed demonstrations, the operator did not achieve a surface of 100% near-white (SSPC-SP 10). Portions of the

surface were rated as commercial blast (SSPC-SP 6) or brush-off blast (SSPC-SP 71. This is attributed primarily to the lack of visibility.

Thus, the poorest cleaning was obtained for corners and bottom edges where visibility was poorest. Overall, the air/water/abrasive slurry blasters gave the best visibility and slightly more thorough cleaning than air abrasive wet blasting. For the- high pressure water-abrasive blasters, 'the operator fatigue and poor visibility-resulted in less well-cleaned surfaces.

Several technical articles and trade literature have asserted that wet blasting methods are superior to dry blasting in removing soluble salts from steel. These salts are often considered to contribute to early rusting of previously exposed structures. However, determining the presence, levels, or effects of the soluble salts was beyond the scope of the present investigation.

For most of the demonstrations, surface profile of the blasted steel was measured using replica tape and/or comparator. The data did not show any difference in profile obtained with wet blasting versus dry blasting.

SAFETY

- The use of high pressure water jetting abrasive blasting can be dangerous. The same is true for the wet blasting techniques, and most of the same precautions must be observed. General safety requirements include dead-man controls on pressurized units, operating within the recommended limits of the air compressor or pump, properly reinforced hose, proper scaffolding, removal of unnecessary clutter obstructions from work area, cordoning off of work areas, and properly trained operators.

Some of the most important safety factors for high pressure water jetting are as follows:

Ear Protection: Typical noise levels are in the range of 90 decibels.
Team versus Single Operation (One organization recommends that single operator be allowed to operate units up to only 2,000 psi; above that at least two persons are required.)
Eye and Head Protection: At the minimum goggles and face shield are required. Full over-the-head hoods may be required in some cases.
Safety Fluid Shutoff: This should be a dump device which cuts off the pressure when the handle is released.
Gradual Increase of Thrust: 'The operator should experience the reaction force (thrust) progressively rather than all at once to start the operation.
Steel Toed Shoes.

There have been several recorded instances where operators have lost a toe or an eye from high pressure water jetting. It should .be emphasized that the high pressure flow rate units have a high operator thrust (40-50 pounds) and may be very difficult to control safely on a platform or other area of precarious footing.

Air· Abrasive Wet Blasting One of the most important safety features is the cutoff valve for the air blast nozzle. In at least one of the demonstrations, operators using defective nozzles were observed. The safety lock, designed to shut off the flow when the grip was released, failed to do so, or aid so sporadically. This demonstrates the importance of proper maintenance of equipment and enforcement of safety procedure.

Although air abrasive wet blasting does cut down considerably on the dust, the use of air-fed respirators is still strongly recommended. There is little documentation on the effect of wet blasting on reducing the level of micron sized particulates in the area immediately around the blaster. Thus, whereas these units apparently are successful in 'controlling environmental problems, they are still considered a possible hazard for worker health. This is particularly relevant in light of the numerous claims on silicosis currently existing against manufacturers of abrasive equipment.

There is little evidence that the use of wet abrasive blasting in any reduces the risk of sparking from the blast nozzle. Thus, their use in tanks or vessels containing volatile materials must still be closely controlled and monitored.

PORTABILITY AND VERSATILITY - This investigation was directed at field cleaning of steel. The ease with which various units can be transported, assembled, and transferred is an important factor in their suitability for certain jobs.

Naturally, smaller cleaning units will require smaller compressors, pumps, and sand .pots and therefore be more easily transported. Weighed against that is the lower productivity rate and efficiency of the low-powered units.

The high pressure water hoses experience a relatively small loss of pressure. This enables the operator to

reach several hundred feet without relocating the pump. For water jetting at elevated heights, supplemental boosters are available to maintain the high pressure. In addition, pressurized sand hoppers can be used to force the sand over large distances of hose.

Air blast hoses for wet or dry abrasive blasting are normally limited to about 100-200 feet unless very large compressors are used. It is generally advisable to place the sand pot as close to the nozzle as possible.

SUMMARY AND CONCLUSIONS

This article described a field evaluation of commercially available wet blast units for cleaning structural steel for painting. The evaluations included, where possible, direct comparison of the candidate wet blast unit with conventional dry sandblasting. The cleaning was conducted on flat surfaces with varying conditions including paint, mill scale, and rust, typicallY l0-15 square feet per trial. from the field evaluations were supplemented by data and information from equipment manufacturers.

The principal conclusions of this work are as follows:

- # Dry sandblasting is overall faster and more effective than any of the wet sandblasting techniques.
- # The units which incorporate water into air abrasive blasting produced cleaning rates up to 80-90s of those of dry blasting and proved very practical for field applications.
- # The units which incorporated abrasives into a medium to high pressure water blast (6,000-20,000 psi1 gave cleaning rates which were only about one-third to one-half that of dry blasting. Because of the high thrust of these units, they would not be practical for extended field use as hand held units.
- # Certain low pressure (3,000-4,000 psi water blasters with abrasive 'addition have demonstrated the ability to remove rust, paint, and mill scale with little operator fatigue. The cleaning rates, however, are considerably lower than that for conventional dry blasting.
- # High pressure water blasting without sand is not capable of removing tight rust and mill scale under normal conditions.
- # All the wet blast units observed produced a significant reduction in the dust.
- # The units observed varied considerably in cost, portability, production capability, and adaptability to existing blast .cleaning equipment. The specific unit to be chosen depends on the size the type of job and the availability of support equipment.
- # Inhibitors are required in the water to prevent flash rusting in most locations. Several types were proven to be effective in controlling flash rusting for at least several hours.

The advantages and disadvantages of the various types of units are listed in Table 3. Additional details are provided in the full report available from the U.S. Maritime Administration or the Steel Structures Painting Council.

TABLE 3
WET BLAST UNITS:
ADVANTAGES & DISADVANTAGES

Unit	Advantages	Disadvantages
Air Wet Blast	High Rates Reduce Dust Retrofit	Extra Hose Sludge Cleanup
Slurry,Blast	High Rates Multi Nozzles Reduce Dust Low Water	Higher cost Additional Operator Sludge Cleanup
High Pressure Water/Abrasive	Greatly Reduce Dust Long Hose. Low Abrasive	Lower Rates High Thrust Poor Visibility High Water Higher cost
Low Pressure Water/Abrasive	Easy to Use Low cost Low Abrasive Low Thrust	Low Rates Short Hose
Ultra High Pressure Water Jetting	No Abrasive Simple Design Cleanest Surface	No Profile Leaves Mill Scale High Water High Thrust

FLAME-SPRAYED COPPER ALLOY COATING FOR UNDERWATER SERVICE: CORROSION CONSIDERATIONS

By

Louis M. Riccio
President
Copperlok, Inc.

ABSTRACT

The Copperlok Coating is a new method of applying copper and copper/nickel to a hulls surface for anti-fouling purposes. The process involves the thermal spraying of a copper nickel alloy onto a specially modified epoxy resin base coat. The alloy in wire form is melted by an oxyacetylene flame, atomized by compressed air and the molten particles are propelled to the surface where they form a strong mechanical bond.

The coating can be built UD to Practical thicknesses of 10 to 12 mils which data shows should last 15 to 20 years on ships where hull speed is in the range of 8 to 12 knots.

Other applications such as off shore structures, power plants and heat transfer surfaces will be presented with slides. -The process and economic factors will be discussed. Samples of the coating will be available for inspection.

COPPERLOK™ LONG TERM ANTIFOULING COATINGS

LOUIS M. RICCIO, PRESIDENT

SEPTEMBER 11, 1985

Hull Biofouling has been a challenge to mariners throughout the history of commercial transport. Early Mediterranean traders covered their hull bottoms with lead sheathing to ward off hard fouling and wood borers.

The British Admiralty in the early 1700's used copper sheathing for the same purpose.

The China Clippers with precious tea cargoes and the clippers running between Australia and Britain with cargoes of wool knew the value of operating with a clean, non-fouling bottom. Using copper and various alloys like Muntz metal which was used on the Cutty-Sark, Fig. 1, consistantly helped this ship to break running records between these trade routes.

The New England Whalers of which samples can be seen today at Mystic Seaport, still wear their copper sheathing. In 1893 the America's Cup defender, Vigilant; used copper alloys and later in 1930 the Enterprise also utilized the benefits of copper alloys. Fig. 2, Fig. 3, Fig. 4. With the coming of steel hulls, copper sheathing gave way to copper based paints. The copper alloy development then centered on alloys with nickel content which offered the best strength and good corrosion resistance. 90-10 copper nickel (CA-706) and 70-30 copper nickel (CA-715) were used in vessels with good success.

With the backing of Copper Development Association and the International Nickel Company, some of the most thorough research to date is "the Copper Mariner's Experience and Economics" report presented in November 1976 SNAME meeting.
A note of particular importance is that the Copper Mariner average corrosion rate of copper nickel over a period of 52 months is less than .05 mils per year [1]. Cladding, sheathing and sheet copper with adhesives are all currently being used with varying successes to reach the main goal: To maximize the anti-fouling properties for longer periods than available now in anti-fouling painted surfaces.

Meeting this goal will benefit the Maritime Industry by lowering maintenance costs and lowering fuel costs. Fuel costs are recognized to account for no less than 50% of the total costs for operating a ship. Marine fouling of a ship's hull can significantly increase fuel consumption. Anti-fouling paints control fouling, but in general their effectiveness decreases with time and re-painting becomes necessary, introducing another cost factor. These factors produce an incentive for the improvement of present anti-fouling paints and for the development of new and innovative coating systems.

Because the previously mentioned methods of applying copper and copper nickel to hulls depend on welding, fitting and tailoring compounds shapes, the idea of using the technique of flame spraying the copper and copper nickel seemed to be a logical solution and this is the patented process employed by the Copperlok coating system.-

This process takes metal in the form of wire or powder, melts it by means of a combustion flame, such as oxygen and acetylene or electric arc, and propels it to the substrate in an atomized condition, by means of compressed air or the velocity of expanding gases as in the case of plasma-type equipment. Of the various thermal spray processes evaluation, the combustion process, with the use of wire, was determined to be the best starting point. Other variations fell short because of cost, excessive heat, complexity, weight and cumbersome aspects of the equipment. Some techniques are being developed further and may, for certain applications, supplant the combustion wire method.

Heretofore, the state-of-art of depositing a metallic coating on a plastic surface consisted of some sort of abrasion, such as a grit-blasting, followed by a coat of an easily deposited coating such as zinc or aluminium. If another higher melting coat was to be deposited, it would be sprayed over the aluminium or zinc or a nickel aluminide coating. The dissimilar metal combinations precluded this technique for marine use. Spraying copper directly on to grit-blasted gel coats can be achieved, but with very poor bond strengths. To build up any practical thickness of 10 to 12 mils would cause a delamination due to the residual stresses of the metal shrinkage overcoming the bond strength. The development of a modified resin coating which provided excellent strength to permit adequate build-up of the flame spray copper nickel coating was achieved after experimenting with various resins and fillers in the form of hollow micron sized silica spheres. Fig. 5. The aspects of water vapor transmission, high temperature excursions, adhesive properties,

along with other constituents to improve wettability, leveling, thixotropic and other properties were part of the epoxy formulation.

Test panels were introduced at the Ocean City Research New Jersey facility'. Emersion tests were necessary to determine if the nature of the oxides might change using flame spray methods and to verify that the anti-fouling properties would remain. No fouling has occurred after the three-year period. Fig. 6, Fig. 7.

Six fiberglass pleasure boats use this Copperlok system to date and two wodden hulls, one of which is an entrant to the B.O.C., 1986/87 single-handed, around-the-world race. Fig.8.

The Copperlok process can be used in G.R.P. new boat construction by applying our bond coat epoxy in the mold first and masking at the water line afterwhich the use of standard laminates completes the hull ,layup. Fig. 9.

After curing and removal of the hull from the mold, the copper nickel thermal spray can be applied below the water line onto the bond coat.

Then applying Copperlok on steel surfaces, the epoxy bond coat with the anti-corrosion coatings, acts as a dielectric barrier and serves to insulate the copper nickel coating from the steel. Fig. 10. In tests at Ocean City Research, it was found that the copper nickel coating had no significant effect on the rate at which the underlying steel corroded at intentional coating holidays when there was no metallic electrical connection between

the copper nickel and the steel. When there was an electrical connection between the copper nickel coating and steel, the steel corroded at the expected rapid rate.[2] A simple alarm system was developed to warn if a short occurs during application of Copperlok. In this system a simple continuity circuit is used to insure that the coating is not shorted to the steel. An alarm sounds to enable the repair or rework of the contact area.

The Copperlok application to the Exxon "Spinel" offshore structure in the Gulf of Mexico demonstrates the typical procedural steps. The coating of a casing pipe is treated as follows: The casing pipe is grit blasted; coated with a moisture barrier epoxy; Copperlok bond coat is applied; after curing, the bond coat is abraded and washed. Copper nickel is then flame sprayed to the desired thickness. Fig. 11, Fig. 12.

The use of current automation techniques will enhance the productivity of applying Copperlok onto piping. Fig. 13. The advantage of Copperlok to coat nodes of offshore structures can readily be seen since the process can be sprayed onto varied contours and shapes. Fig. 14, Fig. 15.

There is a need for anti-fouling coatings in power plant utilities using coastal waters. Coating concrete intake basin walls, concrete pipe, and steel pipe will aid to keep bio-fouling from entering and clogging the condenser tubes. Currently used methods introduce chlorides and bromides into the intake water to keep bio-fouling under control, but chlorine and bromide effluent levels must be monitored closely.

Copperlok coatings can be applied to a variety of substrates and offers to reduce or eliminate the use of bromides.

The Copperlok system lends itself to automation and to the advances in robotic adaptive controls. I believe large hull surface coatings are feasible with relatively short development time. Fig. .16. If our industry is to be competitive in world marine markets, we should readily see the economic benefits to a fifteen year anti-fouling coating.

1) J. L. Manzolillo, E.W. Thiele, A.H. Tuthill, CA-706
Copper-Nickel Alloy Hulls: The Copper Mariner's
Experience and Economics

2) Dynamic Corrosion Testing "COPPERLOK" Coating System,
National Shipbuilding Research Program
U.S. Dept. of Transportation
Maritime Administration in cooperation with
Avondale Shipyards

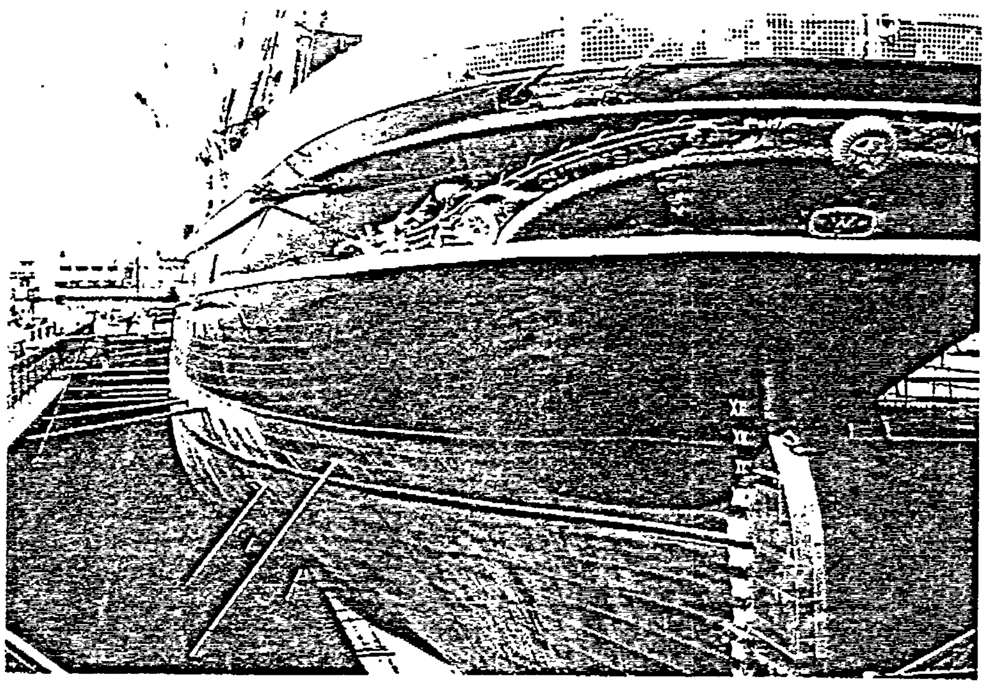


FIG. 1

FOULING RESISTANT PROPERTIES

Initial Corrosion of 90/10 Cu:Ni Produces a Stable and Protective Cuprous Oxide Corrosion Product Film. Complexing with Chloride Ions from the Sea Water Results in Gradual Formation of a Surface Layer of Cuprous Hydroxychloride. This Salt has Limited Solubility, But it is Sufficient To Inhibit the Attachment of Free Swimming Larvae on the Exposed Metal Surfaces.

Source: INTERNATIONAL NICKEL COMPANY, INC.
Corrosion Resistance of Wrought 90/10 Copper-Nickel-Iron Alloy in Marine Environments

FIG. 2

FOULING RESISTANCE — QUIET SEAWATER

Above 3 ft. per sec. continuous velocity—about 1.8 knots—fouling organisms have increasing difficulty in attaching themselves and clinging to the surface, unless already attached securely.

Arbitrary Rating Scale of Fouling Resistance		MATERIALS
90-100	Best	Copper 90/10 copper-nickel alloy
70-90	Good	Brass and bronze
50	Fair	70/30 copper-nickel alloy, aluminum bronzes, zinc
10	Very Slight	Nickel-copper alloy 400
0	Least	Carbon and low alloy steels, stainless steels, nickel-chromium-high molybdenum alloys Titanium

Source: INTERNATIONAL NICKEL Guidelines for Selection of Marine Materials

FIG. 3

MARINE CORROSION CHARACTERISTICS OF WROUGHT 90/10 Cu:Ni

Corrosion Attack Is Minimal, Progressing at a Uniform Rate of .03-.05 Mils Per Year with No Significant Pitting.

Source: INTERNATIONAL NICKEL COMPANY, INC.
Corrosion Resistance of Wrought 90/10 Copper-Nickel-Iron Alloy in Marine Environments

FIG. 4

COPPER-NICKEL

HOLLOW MICRON SIZE

Silcon spheres

EPOXY

COPPERLOK COATING SYSTEM

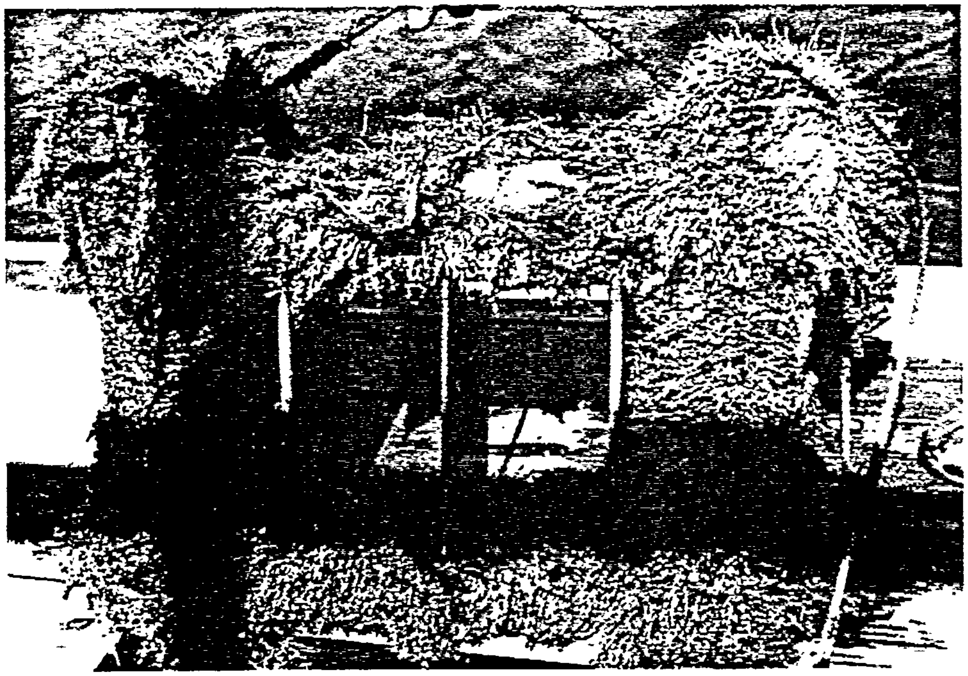


FIG. 6

30 DAY
EMERSION

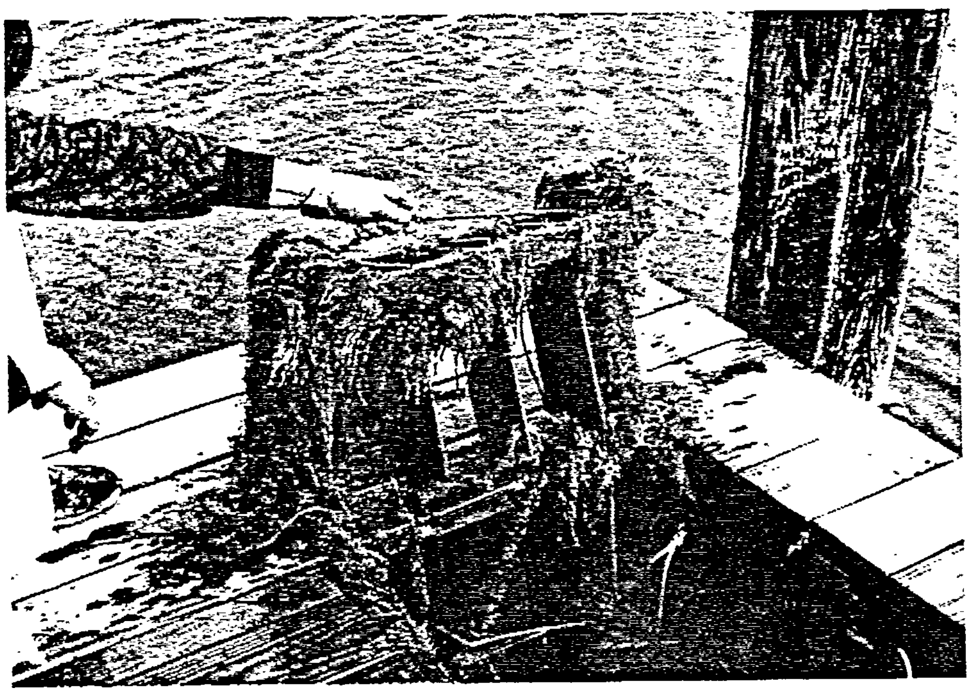
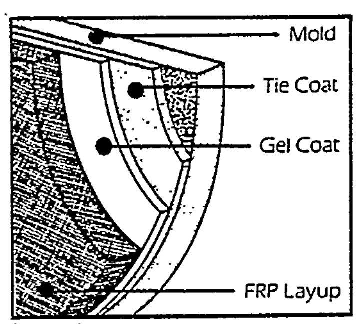


FIG. 7

90 DAY
EMERSION

FIG. 8



In mold application

FIG 9.

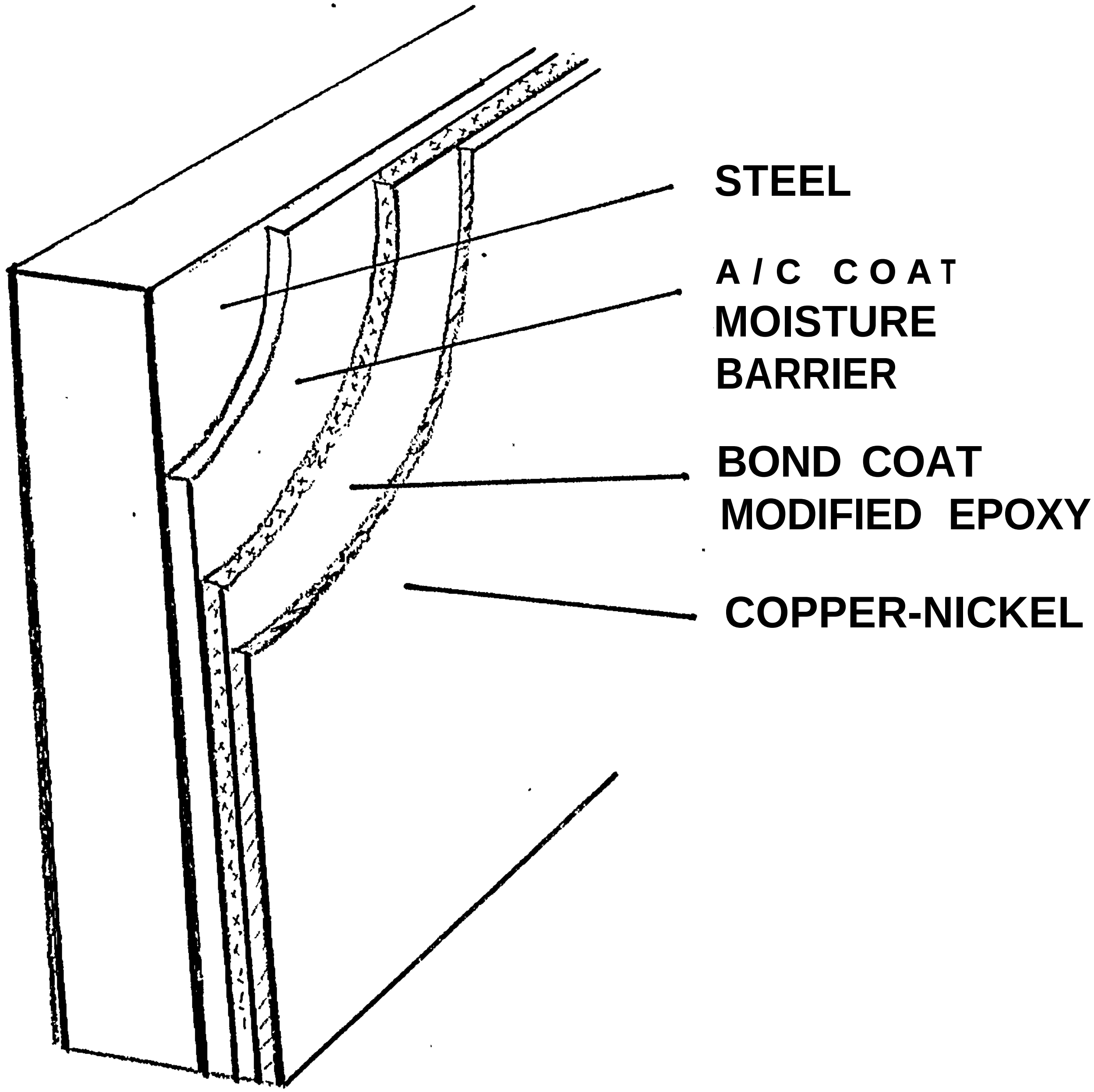


FIG 10

TYPICAL COPPERLOK APPLICATION

FIG. 11

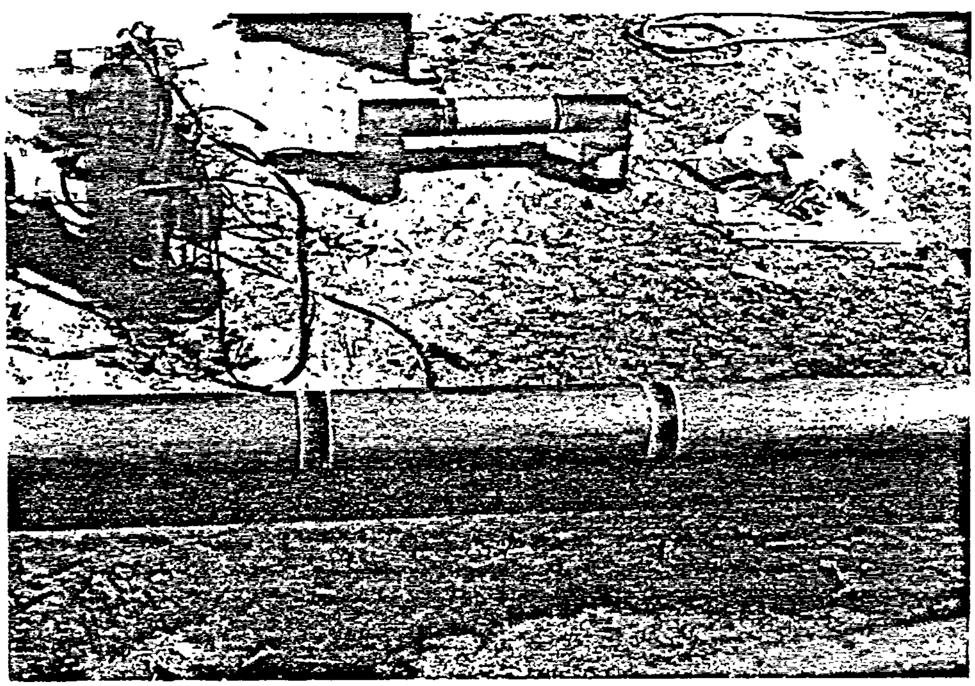


FIG. 12

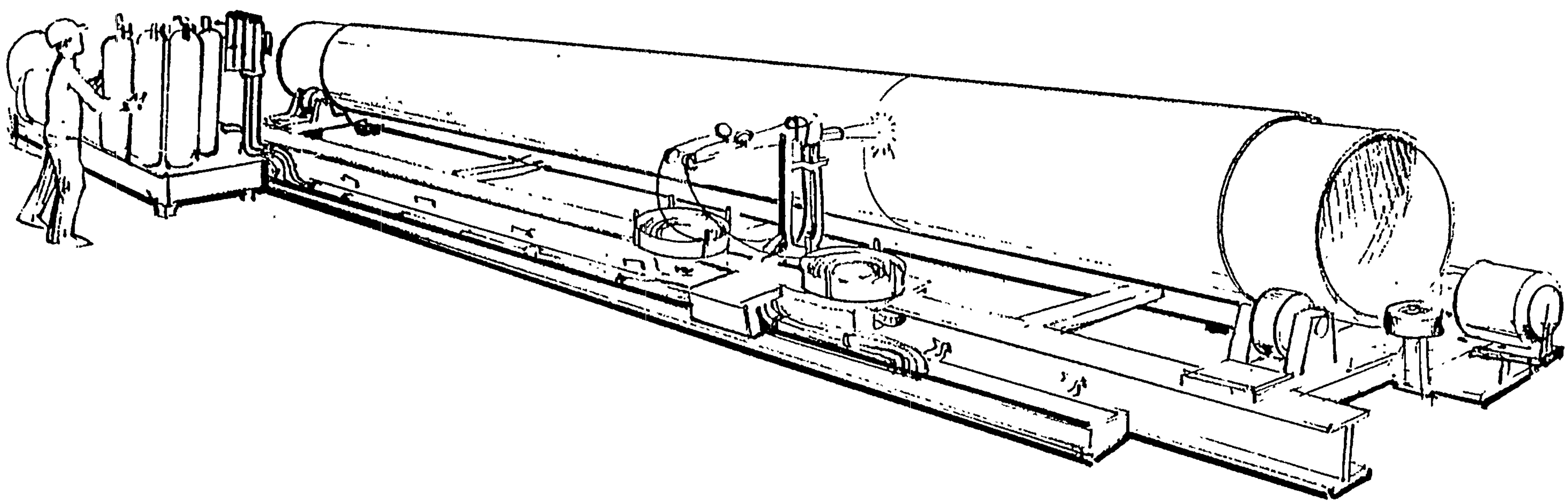


FIG 13

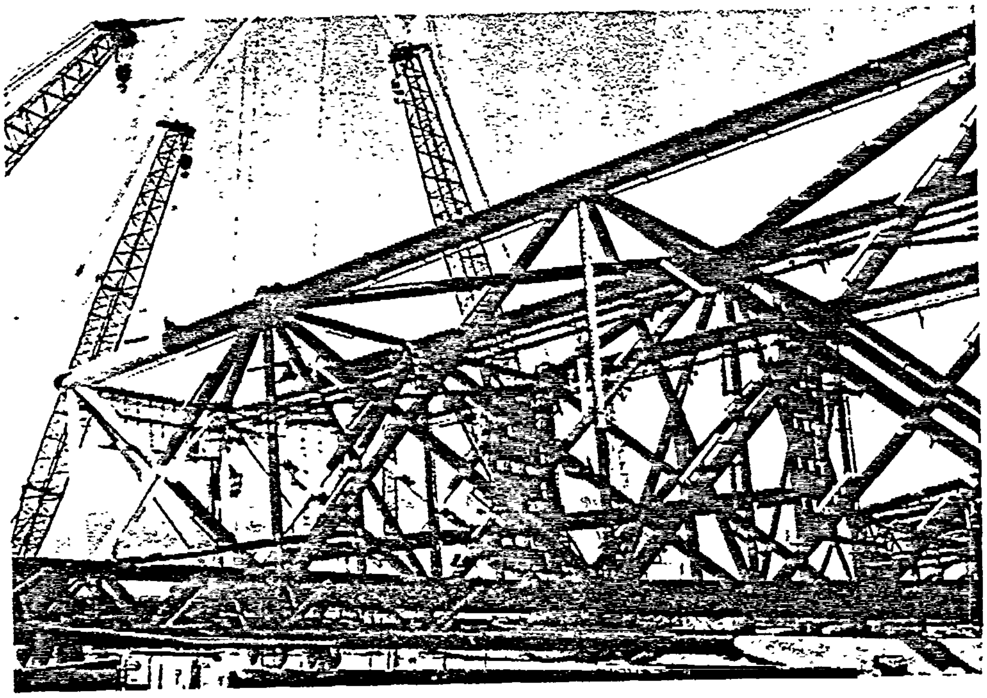


FIG. 14

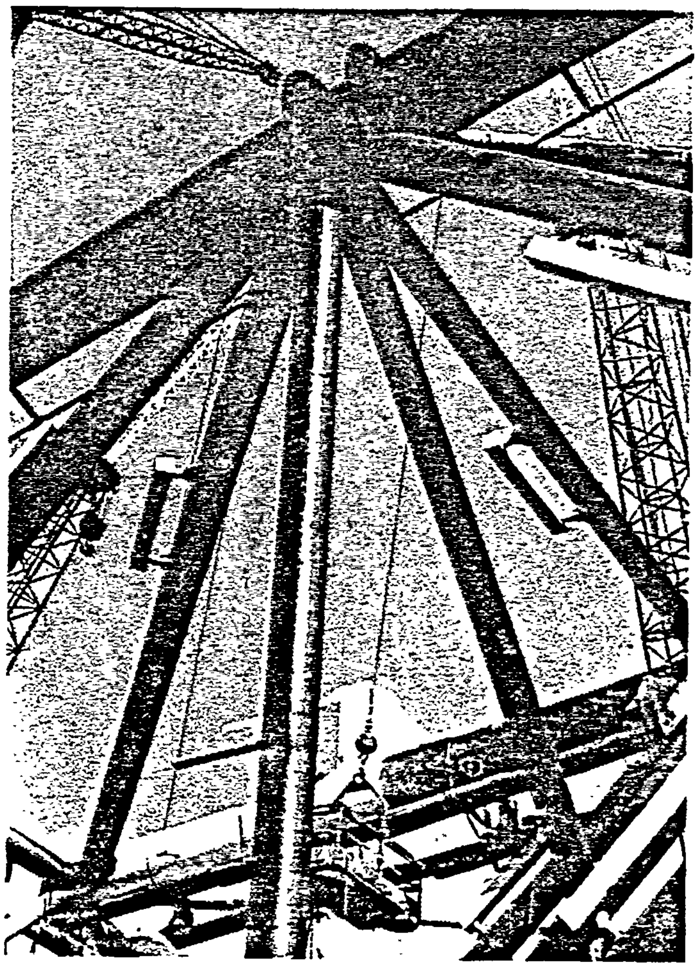


FIG. 15

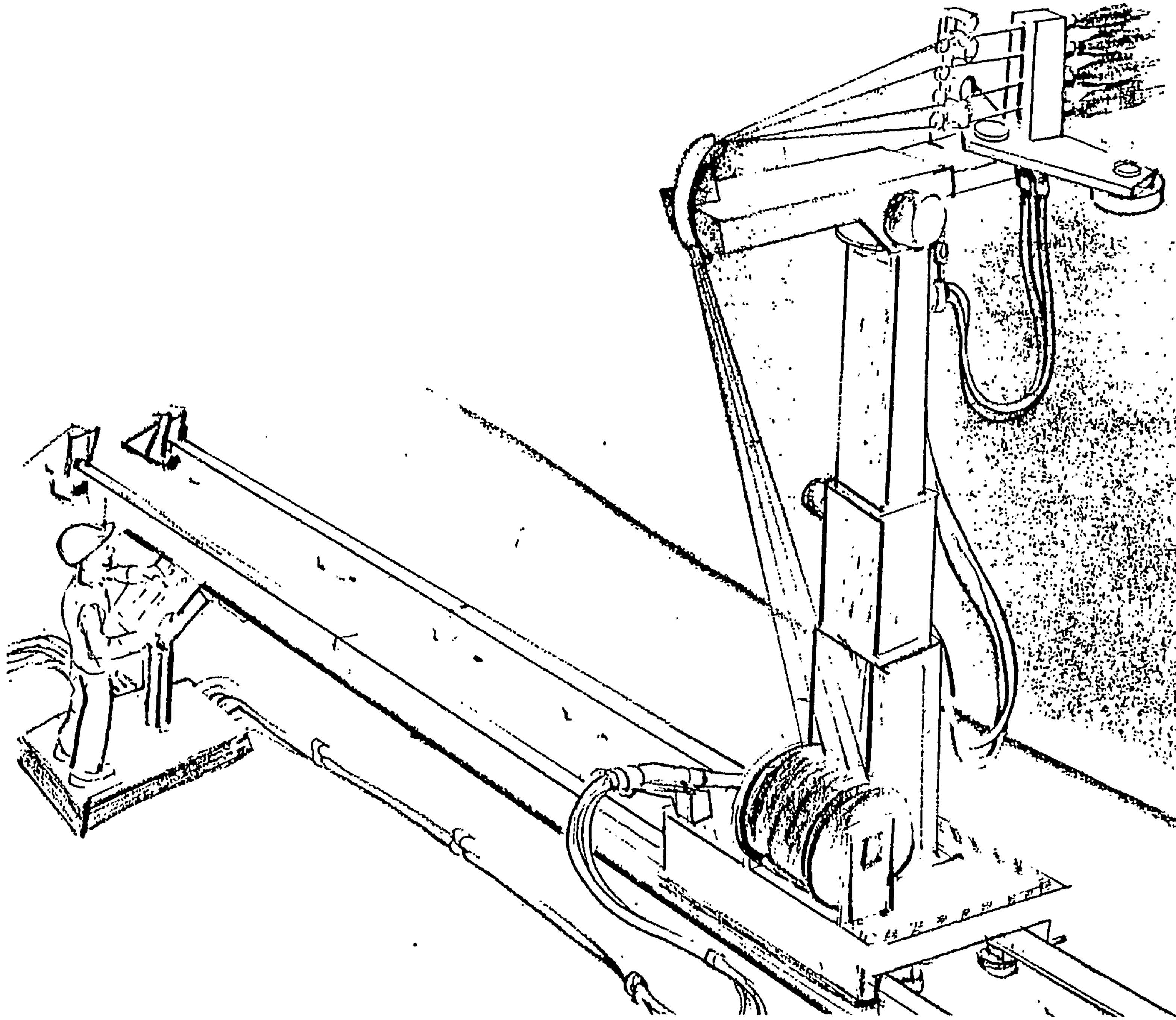


FIG. 14

SPECIAL SESSION

NAVY SHIP PRODUCTION AND REPAIR

John Freund
Naval Sea Systems Command

Chairman

The Naval Ship Design/Prcduction Interface

by

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Director

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Naval Sea Systems Command
Washington, D. C.

September 1985

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The Naval Ship Design/Production Interface

Abstract

The paper discusses, from a ship designer's perspective, some of the current topics and issues relating to the interface between naval ship design and production. The current environment within which naval ship design activity is taking place is described. Notable current views on Navy ship design and how it might be improved are summarized. Navy design topics pertinent to improving ship producibility, operability, maintainability and survivability are discussed and examples from recent ship designs are presented. Issues which result from apparent conflicts in current design initiatives and critiques of the Navy ship design process are highlighted and discussed. Finally, some general conclusions are drawn.

Acknowledgements

The authors are grateful to Mr. Ron Kramer, who collected much of the data presented and otherwise assisted in the paper's preparation. They very much appreciate the inputs and constructive criticisms of the following NAVSEA engineers: Mr. Vic Burnett, Mr. Oscar Hendel, Mr. Ben Lankford, Mr. Bob Riggins and Mr. Charles Atchison. Finally, they wish to thank Mrs. J. D. Oliver, who typed and proofread several drafts of the paper under tight deadlines.

Outline

1. Introduction

2. The Current Design Environment

3. Current Views Affecting Navy Ship Design

4. Some Pertinent Navy Design Topics

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   Shipbuilder Involvement in Design

   Specification/Drawing Flexibility

   Producibility Lessons Learned

   Models and Mock-Ups

   Specifications and Standards

   Computer Supported Design

   Industry Interfaces

   Ship Design Support

   Fleet and INSURV Participation in Ship Design Reviews

   Increased SEA 05 Role During DD&C Phase

5. Issues

6. Conclusions

   References

1. Introduction

Ship design is an iterative, evolutionary process by which an initially ill-defined need is translated into a detailed data package containing sufficient information to permit ship construction. During this process, nearly as much effort is expended on defining the need or "owner's requirements" as is spent on defining the design which responds to the need. Design occurs in an environment constrained by design standards, i.e. rules established by the design agency itself or invoked on the agency by external regulatory bodies. As design proceeds, there is an exponential increase in the amount of detail defined as well as in the amount of effort required to do so. In order to manage and control the process, it has naturally been divided into phases separated by major review and decision points. There are four design phases in the naval ship acquisition world. They are: feasibility studies, preliminary, contract and detail design. Traditionally, the Navy itself has performed the first three of these phases, ultimately producing a contract design data package consisting of specifications, drawings and other data in sufficient detail to enable competing shipbuilders to prepare bids for the task of developing the detail design and building the ship. For this reason, in the world of naval ships Many people, when they refer to the ship design/production interface, are really referring to the interface between the Navy-dominated early stage design world prior to the completion of contract design and the subsequent shipbuilder-dominated world of detail design and construction. This paper will address this Navy-shipbuilder interface.

At the present time, a great deal of attention is focused on the Navy-shipbuilder interface and a number of initiatives are underway which relate to it. Examples of the attention being paid to the subject include the recent publication of Ref. (1) by the Marine Board of the National Research Council and of Ref. (2), contained in the first issue of the Journal of Ship

Production published by SNAME. Refs. (3) and (4) are also noteworthy. Thus it is appropriate for us to examine the reasons for this greatly increased attention and survey some Navy design topics which are pertinent to it. It will not be possible in this paper to examine any of the topics in great depth. However, a broad survey will point the reader toward appropriate references for further study, as well as increase his understanding of some of the current events and issues relating to the interface between.naval ship design and construction. A -greater understanding of our mutual concerns and the,Navy's present needs will enhance the reader's ability to contribute in various ways to improve our methods and approach and, ultimately, the Naval ships we produce. Our search is for ways to improve productivity and, at the same time, to improve the operability, maintainability and survivability of our naval ships.

2. The Current Design Environment

Any difficult task is as strongly influenced by the environment it is performed in as by the skill and dedication of the performer. The environment not only affects the task approach and the numerous decisions made along the way but also how the final product is judged. Naval ship design is no different. The design environment includes a multitude of interest groups, each of which in turn is influenced by a variable environment, as well as impersonal factors such as design facilities, government regulations and the status of emerging technology. The interest groups which affect the naval ship designer's work include those who establish requirements-t the OPNAV sponsor and his chain of command including the CNO and SECNAV, the Ship Acquisition Manager or SHAPM,. the potential shipbuilders, equipment developers and suppiers, those who will inspect the completed ship (the Board of Inspection and Survey--INSURV), the ultimate users--the Fleet Commands, those who must maintain and modernize the ship over its service life--30

years and increasing!-- and, last but not least, the financial backer--the taxpayer as represented by his Congressman. In contrast to the private sector, notable in this list is the large number of interest groups as well as- the fact that it is not clear who is the customer, i.e. is it the requirements setter--the OPNAV sponsor and his chain of command? the Congress? or the ultimate user, the Fleet? This condition makes the designer's task more difficult. The difficulty is further compounded by the fact that the average tenure of key individuals in each of the interest groups is almost certainly less than half of the time required to design, build and test a new naval ship.

The computer "explosion" is a key element of the current design environment. Everyone recognizes that we must utilize the computer, not only to perform design calculations and "keep the books" but also in linked and interactive modes to facilitate the myriad decisions which must be made to integrate a ship design. Linked computer systems are also necessary to maintain and transfer relevant ship design data electronically between parties as a ship design is developed, the ship is built and tested and, after delivery, is operated, maintained and modernized over its service life. Developing the standards, methodologies and facilities needed to do these things will not be an easy task; the task is made more difficult by the diversity of interested parties and the high rate of change of computer technology.

The Navy has unique requirements which are a major influencing factor on naval ship design but are often neglected by those who preach cost reduction and risk acceptance. These requirements reflect young, often inexperienced, and transient crews and ships with long service lives, unusual operating areas, mission profiles which require the performance of principal ship functions at sea rather than in port and, of course, the need to operate in hostile environments. As Admiral Bulkeley so often reminds us, our ship designs must

support the Fleets' ability to perform the Navy's mission: "...Prompt, sustained. . . combat operations at sea."

As is well known, today the commercial ship segment of the nations' shipbuilding business is nearly extinct and there are no signs of an early revival. The Navy workload is insufficient to adequately task all of nation's major shipbuilders. As a result, many are barely surviving and the competition for available work is desperate. It is also widely recognized that the productivity of our nation's shipbuilders-is generally low in comparison to that of the Japanese and better European shipyards.

Pressure to reduce ship cost is increasing as it becomes harder to reach the Administration's goal of a 600 ship Navy in the face of Congressional budget cuts. Ref. (5) presents the Navy plan for acquisition streamlining to save money and thus "not compromise our ability to provide the Fleet with the quantity and quality of weapons systems needed."

NAVSEA resources for performing ship design are also constrained. Space is the most critical problem. The National Center building complex which is NAVSEA's home is overcrowded. There is no space available to assemble collocated design teams. This can only be done by a "force fit", i.e. by displacing people and further compressing the work force. Personnel numbers are also constrained and, in the Engineering Directorates, the manpower available to do ship design is effectively decreasing as management imposes additional engineering duties in the areas of ship construction support and Fleet maintenance and modernization. Computing facilities are only marginally adequate today and there are overwhelming obstacles to computer upgrades both in the procurement process and installation-wise, Space is virtually impossible to find and the lead times and administrative

obstacles involved in obtaining necessary support services in our leased buildings, e.g. air conditioning and electricity, would be literally unbelievable to an outsider.

Finally, the Navy leadership is currently pressing the ship design and engineering community to do a more thorough and professional job of ship engineering. Increased emphasis is being placed on design for ship operability, maintainability and survivability. More effort is being expended on these aspects in our ship designs and top level design reviews have become more frequent and more intense. In part, this is a reaction to past deficiencies; in part it is in recognition of increased future threats.

3. <u>Current Views Affecting Navy Ship Design</u>

Ref. (1) is an excellent report summarizing an exhaustive study into ways by which naval shipbuilding could be made more productive. The Report makes a number of recommendations, some of which are directly pertinent to the current naval ship design process and others less so. A few of the most pertinent findings and recommendations are paraphrased here:

a. Educate Navy engineers in zone-oriented ship construction technology so that Navy practices and procedures can be adapted in support of it.

b. Develop the means to apply zone-oriented ship construction technology in the preliminary and contract design phases, i.e., incorporate production considerations.

C. Minimize the number of contract, i.e. non-deviation drawings, in the bid package. When contract drawings are used, be sure they reflect production considerations.

d. Consider a change in contract design (CD) emphasis based on the shipbuilder's data requirements under the zone-oriented construction approach, i.e. greater emphasis on systems design and equipment selection; less on structural design and ship arrangement details.

e. Produce a firmer design baseline at the end of CD.

f. Create producibility and manufacturing cost design guides to aid prelimina and contract design teams to develop more producible and cost effective designs.

g* Reflect lead and follow yards' inputs in the contract design, e.g. facilities, suppliers, and production methods, to avoid extensive rework (note that necessary design compromises could preclude either yard from obtaining maximum productivity).

h. Establish a task force on computerization in concert with the shipbuilding design and supplier industries to employ electronic media to a maximum extent in design, construction, management and life-cycle support in the next generation of naval ships.

i. Invest more resources in standards development. Convert military specifications to commercial standards wherever appropriate, accelerate the MILSPEC improvment program and use proven foreign or international design standards, to the extent feasible, as the technical basis for U.S. national shipbuilding standards to minimize our own effort.

j. Adjust GFI and GFE schedules during detail design and construction to suit the zone-oriented approach; GFI will 'generally be needed earlier and GFE later than previously. Implement phased issue of GFI.

In Ref. (4) concerning acquisition streamlining, the following points pertinent to the Navy approach to ship design are made:

a. Don't over specify; assume additional justifiable risks.

b. Tailor specifications and contract requirement documents; use a "clean sheet of paper" approach; question all requirements; eliminate the automatic chain-referencing of lower tier specifications; minimize "how to" specifications and emphasize performance requirements.

C. Involve industry in the early design and requirements development phases.

d. Avoid premature setting of requirements; remain open to cost saving options.

Ref. (3) reports upon the Navy's Board of Inspection and Survey's (INSURV'S) findings regarding Fleet characteristics that are the result of past Navy design engineering efforts. Recommendations are made regarding requirements for the engineering of characteristics that support the Fleets' ability to conduct the Navy's mission "... Prompt, sustained...combat operations at sea." The following points are excerpts from the paper:

a. The most rewarding aspect of the recent INSURV design reviews has been the conclusion that once again the General Specifications for Ships of the United States Navy (Gen Specs) play a central role in the development of today's detail ship specifications for Navy ships. The detail specifications for the LHD closely reflect the requirements contained within the Gen Specs. Compared to the loosely written performance specifications used for the LHA-1 Class, the LHD detail specifications represent a marked improvement.

b. Industry will not improve their products until the Navy tells what it wants with well-engineered specifications. Contractors seldom rise above the level of excellence of the engineering inherent in the contract specifications.

C. Navy engineers should conduct warship design through contract design using Gen Specs as the basis for the ship specifications.

d. Engineering feedback is an essential part of the design and engineering process. Testing and correcting deficiencies found during testing is an important part of the engineering process. Classic engineering requires feedback from the user to the responsible engineer regarding the performance of the equipment or system in question.

e. Ship equipments and systems should be selected with operational effectiveness and reliability in mind; then designed into the ship in a manner that does not compromise that reliability; then tested to validate that operational reliability is present.

f. The Navy should be concerned regarding the survivability of all ships. Ships acquired to "commercial standards" are a special concern because they lack not only weaponry for basic defense, but also important features that reduce the consequences of damage. It cannot be guaranteed that such ships will not sustain damage from attack or accident and, therefore, consideration must be given to providing a reasonable package of features to improve survivability. New sealift assets (MSC fast support ships and prepositioned charters) are of concern particularly in view of the dollar value of the assets they will carry.

g More and better maintenance capability engineering should be a feature of future Navy ship designs.

h. Maintenance capability requirements (i.e. accessibility, test equipment stowage, I.C. circuit availability and documentation for alignment, test operations and maintenance) should be clearly visible in the specifications.

i. Space reservations for maintenance access, as well as test equipment and special tool stowage, should be clearly delineated on contract drawings.

Finally, Ref. (6) defines NAVSEA's long range objectives for Hull, Mechanical and Electrical (HM&E) Engineering. The following excerpt is relevant:

"NAVSEA 05 (the Ship Design and Engineering Directorate) will control and be fully responsible for the following throughout the life of a ship:

a. <u>Design</u>

Initial design of the ship and its HM&E systems, including system descriptions, component specifications, shipbuilding specifications, and other technical descriptions. During detail design, and acquisition phases, NAVSEA 05 is to exercise increased technical control through review and approval of key drawings, critical equipment purchase specifications, shipbuilding specification modifications and deviations, etc., to ensure that design standards and requirements are being met by the shipbuilder."

Clearly the recommendations cited in these references reflect a diversity of opinion with respect to what is required to improve our design/production capability. Equally as clearly they identify approaches which collectively contain contradictory guidance which makes it impossible to satisfy everyone.

4. Some Pertinent Navy Desiqn Topics

The following paragraphs briefly describe selected NAVSEA programs or policies which relate to the naval ship design/production interface and are pertinent either to the enhancement of ship producibility or to the recent increased emphasis on improving ship operability, maintainability and survivability.

Education of Navy Personnel

At presen‘t there are no formal programs in the Washington area to train NAVSEA engineers and managers in zone-oriented construction technology and its implications for Navy ship design and acquisition procedures. Many of our engineers and managers have, however, received informal, on-the-job training in this subject in the course of their daily work through their close relationships with, including frequent travel to, shipyards employing such techniques. New engineering recruits to the Ship Design and Engineering Directorate (SEA 05) spend 18 months in a training program, six month of which is field training. Typically three of the six months are spent in a shipyar albeit often a naval shipyard doing repair or modernization work. We also send worki level engineers on one year long term training assignments to private shipyards to study modern ship detail design and construction techniques. In recent years, three engineers have been so trained--one each at Bath Ironworks, Todd !A and NASSCO. Other, special training assignments are often made. For example, a structural engineer was recently sent to the United Kingdom for six months to learn modern GRP hull design and fabrication practices in connection with a new minesweeper design.

In 1982, NAVSEA entered into an agreement with the University of Michigan to establish, within the Department of Naval Architecture and Marine Engineering, a NAVSEA Cooperative Research Program and professorial position in Shipbuilding Technology. One result of this Program has been the development of a curriculum

in the area of shipyard planning, production engineering, and ship design for producibility. Several NAVSEA engineers have taken these courses while attending the University of Michigan for advanced training in naval architecture. Other graduates of the courses have since taken jobs at naval shipyards or other Navy activities.

As a result of the promulgation of Ref. (6) and its emphasis on improved ship operability, a new in-house course is being presented to acquaint our engineers with Human Factors Engineering and how to apply it in the design process. In the same vein, many of our design engineers have attended a two-week summer course in Ship Protection and Weapons Effects. Many other short and long term training opportunities are available, including graduate level courses thru our own NAVSEA Institute.

Shipbuilder Involvement in Design

For at least the past 16 years, shipbuilders have participated in the contract design, and sometimes earlier design stages, of most, and all major, Navy ships. The thrusts behind this participation have been to incorporate producibility considerations into the completed contract design, to gain insight into the shipbuilders' interpretation of specification language, to assign design and/or cost estimating tasks to the builders where their special expertise would prove beneficial and to have additional "pairs of eyeballs" reviewing and critiquing the developing design. The methods employed to obtain shipbuilder involvement fall into the six basic strategies listed below; each has several variants. The first four of these strategies apply to Navy designs: designs controlled and directed by the Navy on a day-to-day basis. The last two strategies apply to industry designs in which the Navy role is restricted to establishing top level requirements and evaluation of the proposed industry designs.

(1) Award support contracts to one or more competitively selected shipbuilders one of whom may be in a favored position to receive the lead ship detail design and construction (DO&C) contract. The selected builders participate in the Navy design effort. Restrict negotiations for the DD&C contract to these shipbuilders. This general approach was used for FFG-7, the Sea Control ship (never built) and, more recently, the MCM and DOG-51, as well as many other designs.

(2) Pay selected builders modest sums to review and critique the Navy design and perform special studies they volunteer for (T-A0 187 approach).

(3) Invite all interested shipbuilders to participate in the Navy design effor at their own expense, either as working members of the design team or in a review-critique capacity at key design milestones. This approach is currently being employed on the SWATH T-AGOS design effort where ten prospective builders are each providing the equivalent of one full time designer to the team. All prospective builders are also invited to participate in design reviews and generally critique the design as it evolves. On the recent AOE-6 design, seven shipyards participated in a reviewing capacity only.

(4) Pay one or more builders to do the contract design under Navy direction (selected either competitively or on a sole source basis) and then negotiate with them for the lead ship detail design and construction contract. This general approach has been used for complex warships such as nuclear powered aircraft carriers and submarines; also for the LHD-1 design--a modified repeat.

(5) The A-109 approach--a competitive, multi-phase, industry design approach from the outset whereby the number of competitors is selectively decreased as the design evolves through several phases. This approach has been used for the LCAC and MSH designs.

(6) The Z-step approach whereby all interested shipbuilders respond to a Navy Circular of Requirements with preliminary/contract designs and detail design and construction proposals developed at their own expense. The proposals are evaluated and a detail design and construction contract is awarded to the lowest bidder whose design and proposal meets all stated Navy requirements. This approach has been used for a number of recent designs , especially conversions and T-ships.

The following paragraphs describe the involvement of shipbuilders in five of our recent design projects.

<u>T-A0 187</u>

A shipbuilder review was conducted for the T-A0 187 program between February and June 1982 before the final reading session and signature of the contract package. Proposals for this review were solicited and the following six shipbuilders were each awarded firm fixed price contracts:

Avondale Shipyards
Levingston Shipbuilding
Newport News Shipbuilding & Drydock Co.
General Dynamics Corp., Duincy
National Steel and Shipbuilding Co.
Bethlehem Steel Co., Sparrows Point

The criteria for award of review contracts were based on the physical ability of the proposer to construct the ship.

The shipbuilders were specifically tasked to accomplish the following:

(1) Review the specs and drawings for errors, ambiguities, and conflicts

(2) Suggest cost reduction items

(3) Suggest improvements for producibility

(4) Suggest further commerciality items.

Though not specifically tasked, some of the shipbuilders asked and were permitted to submit alternate design proposals, e.g. alternate propulsion plants. However, none of the alternates proposed were accepted.

The review was not considered by the Navy to be completely successful for two reasons: (1) the review was unstructured in that the shipbuilders could comment on any system at any time during the review; this greatly complicated the NAVSEA respon mechanisms, (2) the Navy contract design package submitted for review was immature a incomplete. Eventually over 4000 comments were received which proved to be an unmanageable quantity to adjudicate in the short time available. In general, the review aided the Navy effort to correct discrepancies between specification sections and the contract drawings, which would have occurred to some extent without the revi No major design changes were proposed or adopted as a result of this review. Howeve the winning shipbuilder, Avondale, has stated that the review period allowed them time to become very familiar with the ship design which aided the bidding process and allowed them to start detailed design efforts earlier.

AOE-6.

Seven shipbuilders have been involved in the AOE-6 design by their voluntary no-cost participation in a detailed review of the ship specifications, contract

drawings and CDRL (data requirements package) which will eventually make up the final contract design package for the ship. The package was given to the participating shipbuilders in its later stages of development so that the shipbuilders could concentrate on producibility and cost reduction items rather than on technical errors in the package.

The reviews were structured over a 3-month period. In each of the functional areas, major systems were defined and the rationale behind their selection provided. The review approach allowed the shipbuilders to concentrate on selected areas of design during a particular period, i.e., hull systems, or machinery systems, etc. thus maximizing their review efficiency.

The purpose of the review was to insure the producibility of the design, explore ways of reducing ship cost by redesign, specification changes, or changes in requirements (i.e., NAVSEA shipbuilding requirements, not TLR requirements). The manner in which the review was conducted also allowed the shipbuilders an opportunity to understand the rationale behind the design and the reason particular items were specified the way they were.. The dialogue also enhanced shipbuilder understanding of the sources of various requirements, i.e., SECNAV, OPNAV, NAVSEA, Congressional direction, etc., and thus which ones might be changed. Over 200 comments were received from the seven participating shipbuilders which should result in considerable cost savings in the design. From a producibility point of view, many items were accepted such as a reduction in camber in many topside areas and a simplification of fuel tank arrangements and associated piping runs.

There were a significant number of suggestions for structural simplifications which would ordinarily be acceptable for Navy auxiliary ships. However, many of these could not be accepted for the AOE because of the high shock requirements for this ship which will operate with the battle group.

The shipbuilders noted that this review strategy limited their comments regarding producibility and cost reduction ideas because the design was already "cast in concrete".

MCM-1

Two shipbuilders, Peterson Builders, Inc. and Marinette Marine Corp., were selected through a competitive source selection process to participate in the contract design phase under Ship System Design Support (SSDS) contracts. Their involvement was designed to facilitate identifying industry recommendations for producibility and cost saving features. It also served to familiarize the prospective shipbuilders with the design to enhance the validity of their ship construction cost proposals. Both contractors maintained offices close to NAVSEA during the design. Due to delays in the Navy contracting process, the contractor support did not start until the last third of the contract design phase. Yet the shipbuilders provided over 600 specification and drawing comments on the design. Of these, 464 were adopted. Peterson was subsequently selected as the lead shipbuilder and, 'later, Marinette Marine was selected as the follow shipbuilder.

DDG-51

Shipbuilder involvement was emphasized throughout the preliminary and contract design phases of DDG 51 to enhance producibility and reduce cost. CAPT Clark Graham: now at MIT, played a key role in the DDG 51 design and is presenting a paper at this Symposium entitled: "Producibility as a Design Factor in Naval Ships", co-authored with LCDR Michael Bosworth.

Seven shipbuilders expressed an interest in participating in the DDG 51 concept and preliminary design phases and did so. The shipbuilders were: Bath Iron Works,

Quincy Division of General Dynamics, Newport News Shipbuilding Co., Lockheed Shipbuilding and Construction Co., Ingalls Shipbuilding Division of Litton Industries, Los Angeles Division of Todd Pacific Shipyard Corp. and the Seattle Division of Todd Pacific. They conducted more than sixty studies involving shipbuilder-proposed alternatives and trade-off candidates.

During the concept design phase, these shipbuilders looked at broad topics, including a review of the current baseline, to identify potential design changes for cost reduction or easier production. Topics studied included an assessment of the effect on acquisition cost of a reduction in molded deck heights and in passageway volume, and analyses of the cost benefits of incorporating various degrees of shipboard data multiplexing, of applying metric standards throughout the ship, and of using a computerized data base for contract design.

During-the preliminary design phase, the shipbuilders looked at the tightness and volume sensitivity of the electronics/controls complex, the machinery box, and the passageways and accesses. Concepts evaluated included:

- o minimum deck heights and widths,

- o modularity of combat system equipment to standardize and simplify installation,

- o minimizing structural depth in way of decks with false floors,

- o recessing the pilot house into the radar complex,

- o vertical distribution of combat system support services using armored trunks,

o mast designs to minimize weight,

o modularity and pre-outfitting of machinery and auxiliary equipment and of piping systems,

o effects of using lightweight cable,

o installation of GRP joiner bulkheads,

o recessing equipment mounted in passageways,

0 mounting equipment , usually outside of the ship, inside to reduce topside maintenance.

Three shipbuilders with current combatant ship construction experience, Bath, Ingalls and Todd, were selected to support the design effort during Contract Design. Each shipyard supplied a four-man team (team leader, weights, system engineering, cost) to work on-site as part of the design team, a feature unique to the DDG 51 design effort at the time. Shipyard personnel rotated in the system engineering slot and came with expertise in structures, combat systems, computers, outfitting, and other specialties as the need arose. Their on-site support included review and evaluation of emerging design data, performance of additional trade-off studies to enhance the producibility of the design, development of cost and weight estimates, trade-offs-of individual systems or components , participation in drawing board. reviews, and attendance at Navy reading sessions and quality assurance reviews of -the specifications and CDRL items .for the initial RFP draft. Participation by shipbuilders in the reading sessions gave valuable insight to the Navy specification

writers as to how the eventual user would interpret the words in the Ship Specifications and the information presented in the drawings.

During the DDG 51 contract design phase, a full time Navy producibility engineer gave focus to the producibility effort and ensured that all concepts and cost saving proposals generated by the shipbuilders were reviewed and evaluated. His responsibilities included coordinating and documenting the information provided by the shipbuilders, identifying specific topics for shipbuilder investigation, and obtaining estimates of cost savings and schedule reductions for proposals submitted.

A bit of design history is interesting to illustrate the difficulty associated with optimizing a contract design for producibility. An effort was made to identify module breaks during the DDG 51 contract design so that space arrangements, equipment layouts, structural configurations and distributive system layouts could be defined with the break locations in mind. However, due to differences between the three shipbuilders* facilities and methods, it was not possible for any two of them to agree on break locations, let alone all three! They agreed to disagree. Consequently, the contract design was completed without any assumed module break locations.

During the DDG 51 contract design, NAVSEA conducted a course on specification preparation. Attendance of the shipbuilders on the DDG 51 team as well as Navy design engineers was encouraged. The course was so well received by the shipbuilder attendees that it was repeated at the shipyards, thereby enabling many more shipbuilder personnel to become familiar with the Navy's practice in preparing specifications and related documents.

References (7) thru (12) contain additional information on the role of the shipbuilders in the DDG 51 design.

LHD-2

The LHD class was selected as one of four Navy Programs to receive special emphasis at the outset of the Acquisition Streamlining Initiative. Accordingly, in February 1985 NAVSEA issued a draft RFP with Specifications and Drawings for the Follow Ship Detail Design and Construction Contract to each potential shipbuilder for review and comment. The purpose of this review was to solicit shipbuilder comments to "tailor" the specifications and drawings to enhance ship producibility, i.e, change the specifications to define the ship in a way to reduce cost, facilitate production, etc., without jeopardizing operational or performance capabilities. A total of 716 questions and comments were received of which 49 were technical or design-related (specification-drawing clarification and interpretation). The comment included proposals to specify commercial in lieu of MIL/FED specifications and to delete certain deliverables. No comments were considered major, probably due to the short time allowed for shipbuilder review.

This concludes a description of how shipbuilders were involved in five recent ship design projects.

Specification/Drawing Flexibility

The T-A0 187 Class oiler design was one of the first Navy ship designs in which the shipbuilder was given flexibility in developing the hull shape and structure. Both the midship section and lines drawing, historically contractual, were issued as guidance documents although the general arrangement was maintained as a contract drawing. The shipbuilder had to satisfy ABS rules, meet speed, design the propeller, and conduct model tests in order to satisfy mission requirements. He was permitted to optimize the design to best meet his own production methods.

Producibility Lessons Learned

NAVSEA engineers receive feedback from SHAPMs, SUPSHIPs, and directly from shipyards regarding producibility problems. We continually look for ways to improve our ship designs to facilitate the use of less costly and easier construction methods. Much feedback comes from official change orders which are screened for application on subsequent designs. During a new design all these lessons learned are considered. Some examples: on a new design the deck heights are studied to ensure they are adequate to readily arrange and install ductwork, equipment, etc. Straight, in lieu of parabolic, camber has been used as a result of feedback from shipyards. The structural designers over the years have reduced the number of different sizes of stiffeners to save costs, based on comments provided by shipyards. Machinery arrangements consider problems with construction and maintenance access. Many functional codes have developed internal guidance documents for design so that such lessons learned can be applied to future designs.

Models and Mock-ups

During contract design, NAVSEA often develops scale models to determine machinery arrangements, complex pump room layouts, piping runs, etc. to assure producibility and maintainability. Full scale mock-ups are generally done during detail design and NAVSEA specifies the requirement in the ship specifications. Though primarily used in assessing operating and maintenance aspects, mock-ups are invaluable tools for producibility studies too, especially in machinery design and submarine tank construction.

Specifications and Standards

A consensus has developed that a complete set of National Shipbuilding Standards

is needed to support a competitive U. S. shipbuilding industry. A program to accomplish this has been developed and is underway. The SNAME Ship Production Committee Panel SP-6 establishes Program policy and ASTM Committee F-25 on Shipbuilding is developing the Standards. The program is described in Appendix C of Ref. (1). The Navy actively supports this program with the objective of converting many existing Milspecs and other Navy standard documents to commercial industry standards. An approach has been adopted to deal with unique Navy requirements in a particular area which simply cannot be incorporated into a broadly acceptable commercial standard. The approach is to develop Navy or DOD Addendums to the industry standards. Problems associated with the program from the Navy's perspective are its manpower requirements and the length of time required to develop and issue agreed upon standards.

Three other NAVSEA spec-related programs are notable. We are planning major emphasis on the Specification Improvement Program with the objective of ensuring that NAVSEA cognizant specifications, standards, and standard drawings are current with the state of the art and remain up-to-date. The program has been underway for several years. Each year the documents needing revision are prioritized and the most urgent ones are rewritten or updated to the extent funds are available. As of September 1985, of the 8200 documents for which NAVSEA is responsible, 1100 are being revised and 2100 require major revision and haven't yet been acted upon. FY 85 funding for the Program totalled about 812M.

Another NAVSEA effort which has been started is the development of a so-called "Commercial Gen Spec". Such a document would facilitate the development of tailored specifications for NAVSEA ship designs based wholly or extensively on commercial standards and practices. In the past in such cases, NAVSEA has attempted to use the MARAD Gen. Spec. as a basis for spec preparation but this has proven to be unsatisfac The format of the MARAD specification does.not correspond nearly as well to the NAVSI

engineering organization as does the Ship Work Breakdown Structure (SWBS) of the Navy Gen Spec. Thus, in assigning responsibility for specific sections of the MARAD spec, there are many "split" sections. This leads to confusion and some important aspects inevitably fall through the cracks. Another problem is that the MARAD Gen Spec has not been kept current with technological advances and recent changes in shipbuilding practices. NAVSEA management has identified initial funding and in-house manpower to execute this program. Estimates are that about $200K will be required to develop the initial version of the document and about $1OOK per year thereafter for maintenance and updates. So far, a first draft of the document has been created.

For the past two years NAVSEA has been working on an in-house project to identify and highlight our most critically important ship design standards--those principles deemed most vital to ship effectiveness, safety, operability, maintainability and survivability. The idea is to make these standards highly visible to our executives, acquisition and design managers and the engineering work force so that it is less likely that they will be overlooked or overruled by the direction of a mid-level design or acquisition manager. The standards are purposely succinct and quantitative--a sort of "Ten Commandments" of NAVSEA ship design. In many cases they reference more extensive specifications, Design Data Sheets, Technical Practices Manuals or other pertinent information. To date, 36 design standards have been approved covering such topics as longitudinal hull strength, ship service generator sizing and selection, freeboard and anchor system sizing and selection.

Computer Supported Design

The NRC report "Toward More Productive Naval Shipbuilding", Ref. (1), recommends the Navy should ". ..employ electronic media to a maximum extent in design, construction management and life-cycle support in the next generation of Naval ships." (P. 6)

"Employ electronic media to a maximum extent in design" is a pretty fair synopsis of the mission of the Computer Supported Design (CSD) Project which its Director, Mr. Kit Ryan, will describe in another paper at this symposium.

The Computer Supported Design (CSD) Project was established about two years ago by NAVSEA to develop a fully integrated, computer-based ship design system. The system is to permit the development of ship designs from conception through the end of the contract design phase. The original objective was to develop the system in five years but more time will be required due to funding shortfalls. Progress to date has been slow but encouraging.

There are substantial parallels, especially in the configuration definition area, between computer applications for design and computer applications for construction and life cycle management. Since the latter is also a SEA 05 responsibility, CSD has been active in establishing the technical and contractual mechanisms for data transfer by working with Navy and industry representatives, particularly in association with DDG 51 and SSN 21 design efforts.

Computer systems available today offer a means of design communication which is significantly more complete and less ambiguous than the engineering drawing. To appreciate this change, one needs only to consider the improvement in communications quality of the engineering drawing as compared to its predecessor, the written or verbal instruction.

As with many aspects of modern life, this change has arrived with stunning speed. CAD models reflecting any part of the design can be generated today on many computer systems. Furthermore, a number of systems have the capability to

reflect many attributes and connectivities at a near-product-model level of definition. The Initial Graphics Exchange Standard (IGES) currently offers a substantially complete method of communicating the geometric portion of these models between systems and promises to be expanded into other areas of the product model transfer.

CAD system costs are rapidly diminishing. Knowledge of how to integrate these systems into the design process is rapidly growing and spreading. CAD models will be the routine method of reflecting design integration within four years and product models will be standard within eight.

The CSD Project Director, Mr. Ryan, is an active member of the CAD Panel of the SNAME's Ship Design Committee. This Panel is our principal vehicle for interfacing with industry regarding the CSD project development. Virtually all ship design agents and shipbuilders are represented.

Industry Interfaces

NAVSEA actively supports the efforts of the Technical Committees of SNAME to improve the productivity of the U. S. shipbuilding industry, to improve our ability to design ships and to enhance the integration of ship design with production. NAVSEA is represented on both the SNAME Ship Design and Ship Production Committees as well as all of their Panels concerned with issues of interest to NAVSEA. Pertinent to this discussion is our membership on the Ship Design Committee's Panel SD-Z (Computer-Aided Design) and the Ship Production Committee's Panel SP-4 (Design/ Production Integration) and SP-6 (Standards and Specifications) as well as ASTM Committee F-25 on Shipbuilding and its technical subcommittees (the latter are involved in the National Shipbuilding Standards Program). We would welcome invitations for further participation in areas where that is deemed desirable.

Ship Design Support

During the past two years, NAVSEA has implemented a new approach to contracting for ship design support. The thrust behind this initiative has been to improve the quality of our ship designs and, at the same time, to increase the competition for ship design support work (i.e. eliminate sole source tasking). In the past we have had identical Level of Effort type contracts with a large number of firms to provide ship design and other engineering support on a task basis. In principle, tasks were to be competed among the firms but, in fact, most tasks were processed on a sole source basis since less administrative lead time was required (4-6 weeks vice 6-10 weeks for competitive tasks): The primary disadvantages of this approach were the high percentage of sole source tasks and the lack of continuity in contractor support, i.e. a specific type of work was tasked to many different firms at different times depending upon workload, individual task leader preferences, etc. The effects of this lack of continuity were that product quality suffered due to the lack of sustained "lessons learned" feedback. Also, inordinate amounts of time were spent by Navy engineers in training contractors.

Under the new approach, competition takes place "up front" for pairs of contracts awarded in each major functional area of the Ship Design and Engineering Directorate. The number of firms providing support in a given functional area is reduced to two prime contractors and they do all of the work, i.e. fleet support as well as new ship design, detail design and construction support, and modernization/conversion design. Thus training is facilitated, the contractors are exposed to all fleet feedback and the reflection of this feedback into our ship design and modernization efforts is enhanced. Sole source justifications are eliminated; the Technical Manager of each pair of contracts decides which firm is to be assigned a specific task without needing to justify his decision to higher authority. Incidentally, one pair of these contracts provides for design

integration support and also enables us to contract with a single firm for an entire preliminary and/or contract design of a so-called "Lo Mix" ship. Such designs are straightforward designs of a T-ship or Navy auxiliary ship or service craft where we don't want to involve the entire engineering organization due to the press of higher priority engineering work.

Fleet and INSURV Participation in Ship Design Reviews

For many years it has been standard procedure to solicit Fleet comments on the contract design specification and drawing package prior to completion. Recently, it has been found that this procedure alone is inadequate. Fleet commentors have been handicapped by a lack of understanding of the design requirements and critical design issues and how they were resolved. Faced with the sudden delivery of a huge package of specifications and drawings without adequate explanation, it might be expected that the comments received would tend to be relatively minor ones, prepared by a low ranking staff member. In order to enhance the substance and hence the value of Fleet design review inputs, efforts are now routinely made to provide briefings on the design to key Fleet personnel prior to soliciting review comments. Also Fleet representatives are invited to NAVSEA design team reviews as well as Independent Design Reviews. The Fleets have responded well to these initiatives and on recent designs Fleet comments of great value have been received. Three recent examples are:

LHD-1 Fleet Reviews

Fleet representatives were invited to attend and participate in a series of "In-Process Design Reviews" throughout the contract design phase (one every 6 weeks). COMNAVSURFPAC and COMNAVSURFLANT representatives, as well as COMPHIBGRUWESTPAC,

COMTACGRUTWO, COMPHIBGRU TWO and various ship operators, including the CO and XO of an LHA, attended. The Fleet Representatives questioned various design decisions and provided first hand ship operating experience and suggestions to change design features that were marginal or "bad actors" in the fleet. This face-to-face review between NAVSEA, the Fleet and the shipbuilder proved to be very valuable.

A "Lessons Learned" document was developed which identified over 250 reports of LHA deficiencies (i.e. various Fleet reports, CASREPS, etc). This document was updated to reflect comments received from the Fleet during the In-Process Contract Design Reviews. This document was incorporated in the Contract Design and Detail Design Contracts for shipbuilder action, to resolve and report corrective actions taken to NAVSEA. These reports were included in the ISD In-Process Design Reviews.

AOE-6 Fleet Review

An independent design review was performed during the contract design phase. The ten Fleet members of the review team represented SERVGRUONE, SERVGRUTWO, NAVSURFLANT and NAVSURFPAC. A number of excellent comments were received and many were incorporated as shown in the following Table:

	Incorporated	Partial/Pending	Rejected	Total
Major Comments	11	4	3	18
Significant Comments	8	5	2	15
General Comments	42	'14	11	67
	61	23	16	100

Details are provided in Ref. (13).

DDG-51 Fleet Review

A formal Fleet review of the DDG-51 contract design was conducted in mid-April 1984 with CINCLANT/PAC and SURFLANT/PAC participating. The contract design spec and drawing package was provided to the reviewers beforehand. The review was a success in that the Fleet representatives gained a much better understanding of the design and, in turn, made a number of useful suggestions for improvements.

INSURV Design Reviews

Early in 1983, a new initiative was undertaken by NAVSEA and INSURV. This was to have INSURV review Navy ship designs on-site prior to award of the ship construction contract. Previously, INSURV had always been asked to review completed contract designs without interfacing with NAVSEA engineers. Lacking knowledge of the design history and rationale for many design decisions, the INSURV comments were generally of limited value. With the greater knowledge that comes from face-to-face meetings, it was felt that INSURV's familiarity with the problems of our operating Fleet would make their review comments especially valuable. This has proven to be the case.

LHD 1 was selected to be the first ship to be reviewed on-site by the INSURV Board during the Contract Design Phase. INSURV produced 497 action items as a result of their analysis from 16 to 20 May 1983. Many of these items resulted in modifications to the design, others were earmarked for action during the detail design phase and were invoked as part of the detail design and construction contract.

This initial review was followed by an INSURV review of the DDG 51 contract design. The December 1982 preliminary design baseline was informally reviewed

in March 1983, the INSURV review team received a two-day informational brief on the contract design in Sept. 1983 and, finally,-the completed contract design was formally reviewed during the week of 2 April 1984. As a result of the latter review, 268 recommendations were made, of which 175 were adopted.

Most recently the MSH design, developed by Bell-Halter, was reviewed in June, 1985. Again, a number of valuable comments were made.

The INSURV design reviews have proven to be an especially effective way to interject "lessons learned" from numerous inspections of the full spectrum of Navy ships into new ship designs <u>before</u> they are completed.

Increased SEA 05 Role During DD&C Phase

As previously mentioned, Ref. (6) established as Command policy that the Ship Design and Engineering Directorate would exercise increased technical control during the detail design and construction phase to ensure that design standards and requirements are being met by the shipbuilder. As a result of this direction, the number of CDRL deliverables to be reviewed and approved by NAVSEA instead of the Supervisor of Shipbuilding is substantially increased on the DDG 51 over previous designs. For example, the following Table contrasts DDG 51 with CG 47:

Number of Deliverables

	CG 47	DDG 51
NAVSEA Review.(1)	295	639
NAVSEA Approval	166	401

(1) Total, including deliverables for approval

There will also be increased Engineering Directorate involvement in design reviews, especially in the areas of interior communications and combat system integration.

5. Issues

Based on the preceding discussion, three issues related to the ship design,/ production interface appear to be worthy of note. These are:

- o Specification philosophy
- o Approach to shipbuilder involvement in PD/CD
- o Degree of Contract Design definition

Specification Philosophy

For many years, most naval ship specifications have been based on the General Specifications for Ships of the United States Navy, i.e. Gen Specs. This document has evolved over the years as lessons have been learned, often harsh ones, and technology has advanced. Gen Specs is a mix of "detail" and performance-type. specification requirements; in many instances, a successful way of doing something has been found, along with many unsuccessful ways, but no one has been smart enough to write a performance specification which would embrace the successful method but exclude the known unsuccessful ones. Gen Specs is generic and broadly applicable to the full spectrum of naval ships; it is carefully tailored to each specific ship during the ship's contract design phase. Gen Specs and tailored ship specs based upon it typically invoke a large number of lower tiered specs and standards which have similarly evolved over time to reflect lessons learned and technological advances at the system and equipment level.

The guidance received to date concerning the DOD acquisition streamlining initiative is apparently at odds with our traditional approach to developing naval ship specifications. Such injunctions as "use a clean sheet of paper approach", "eliminate the automatic chain referencing of lower tier specifications", "question all requirements" and "minimize 'how to' specifications", all would appear to suggest that the Gen Specs approach is no longer deemed acceptable.

Another apparent specifications conflict arises as a result of one of the major thrusts of the comments and recommendations made in Ref. (1) that our contract design baselines must be firmer, i.e. specifications must be more detailed. Again, "firmer contract design baselines" would appear to be at odds with the acquisition streamlini injunctions of "don't overspecify", "use a clean sheet of paper approach*', etc.

Considerable attention is being given to these apparent conflicts within the Navy's ship design and acquisition community at this time. Note the use of the word "apparent". The authors are optimistic that, in fact, there are fewer contradictions in this area than might first appear to be the case.' Indeed we believe that much good will come from the current soul searching and debate. We cannot walk away from the hard won knowledge reflected in the Gen Specs, knowledge often won at the expense of American sailors' lives, but at the same time we cannot afford to blindly lock ourselves in to archaic or simply unnecessary requirements when a fresh look would show that modern technology will permit a fully satisfactory and more cost-effective solution. The acquisition streamlining injunctions are telling us that we must take that fresh look in all of our current and future designs.

Approach to Shipbuilder Involvement in PD/CD

As discussed earlier, in recent years, shipbuilders have routinely participated

in the contract design and, less frequently, in the preliminary design of Navy ships. In the authors' view, a prime motivator for this involvement was a desire to defuse the adverserial relationships (and claims) which characterized naval shipbuilding during the 1970s. Whatever the rationale, there are three potential generic advantages to increased shipbuilder involvement:

o To incorporate producibility considerations into the design in order to reduce construction costs.

o To gain insight into the shipbuilders' interpretation of the specification language in a non-adversarial setting in order to reduce ambiguity. A very worthwhile objective, but also, candidly, a "claims avoidance" tactic.

o To improve the overall quality of the design by exposing it to critical review by outside experts.

The above advantages pertain mainly to shipbuilder involvement during ship designs conducted by NAVSEA. In addition, the coin can be reversed, and the ship can be designed by industry, with varying degrees of NAVSEA involvement. Each of these approaches has pluses and minuses (and proponents and opponents), and there is likely no textbook solution applicable across the board.

From the producibility standpoint, the authors have not seen clear evidence that shipbuilder involvement in early stage (preliminary) design is necessary; The Ship Production Committee's Panel SP-4 "Design for Production Manual" Ref. (14), has numerous examples of how to reduce ship cost by designing for producibility. The examples are a mixture of early stage and detail design considerations. However, the early stage design considerations are broad concepts which can be applied based

on design guidelines, and do not require shipbuilder involvement in specific designs. We support the need for the Navy to apply producibility considerations in early stage design and we need the shipbuilding industry to tell us what these considerations are. But, that is not a sufficient basis for arguing that direct shipbuilder involvement in specific preliminary designs is essential.

In the authors' view, NAVSEA will continue to design the majority of the Navy's ships, and the principal issue to be determined in each specific design will be the range and depth of the shipbuilders' involvement. Whichever approach is "best" for an individual design is a function of a number of variables.

The approach used on MCM and DDG-51 was to competitively select a relatively small number of shipbuilders to assist NAVSEA in the contract design effort. Since competition for the lead ship detailed design and construction contract would be restricted to these shipbuilders , each of them was motivated to really dig in and become highly knowledgeable about the design. Typically, this approach produces excellent suggestions to improve both the quality and the producibility of the design. From the shipbuilders' vantage point, even if they did not win the lead ship contract, they-would still be in an excellent position for a follow ship award. Disadvantages of this approach include increased design *costs* (hopefully, more than compensated by construction savings), and the time required to competitively select the shipbuilders (this can be done in parallel with the NAVSEA preliminary design effort). This approach is also consistent with the NRC study (Ref. 1) recommendation to reflect the lead and follow shipbuilder's inputs in the contract design.

Another approach is to invite a larger number of shipbuilders to participate, and to only partially compensate them for their efforts. This technique is usually employed for those less complex ships where the number of potential shipbuilders

is relatively large, e.g. T-AO 187 employed this approach. From the Navy's viewpoint, this approach is administratively quicker to put in place, and it is cheaper, at least in near term costs. And it is of course to the potential bidders' advantage to gain early insight into the Navy's design. But it can be argued whether or not this approach has the potential to achieve the three goals listed above. Market place factors will likely determine the degree of shipbuilder involvement.

Another concept, currently being employed in the SWATH T-AGOS design, is to invite ALL interested shipbuilders to participate in the NAVSEA design effort at their own expense. In the case of SWATH T-AGOS, the shipbuilder representatives are actually working members of the ship design team. This is not a prerequisite for lead ship award, but the number of interested shipyards is still high. SWATH T-AGOS may be a unique case because of the desire to get in on the "ground floor" in view of the Navy's current great interest in SWATH ships , and because of the very large number of shipyards capable of constructing this "low tech" ship. A variant of this approach was employed in the case of AOE-6, where shipbuilder participation was restricted to a review/comment mode only. Participation by industry was excellent and produced good results, with minimum cost and schedule impact to the Navy. However, the shipbuilders felt that their comments could only be minor and have limited impact since the design was already "locked-in".

Involving all interested shipbuilders as working members of the design team will certainly cause ship producibility considerations to be given greater weight than simply requesting them to review and comment on an essentially complete-design. However, the design cannot be tailored to the unique inputs of the potential lead and follow shipbuilders (since all potential builders can participate) and there is a real possibility that a shipbuilder with no real chance of winning the construction

contract might bias the design unfavorably from the ultimate winner's point of view simply because of his influence on the area of design he worked on.

A more sweeping approach is to pay the shipbuilder (or shipbuilders) to actually conduct the contract design (and perhaps even the preliminary design), but under Navy direction and control. Such contracts can be awarded competitively (a lengthy process) or sole source if unique capabilities are required. In this approach, the shipbuilders are fully compensated, and are obviously in a good position for award of lead or follow ships. There is additional design cost for the Navy if more than one shipbuilder is involved and additional time may be required for the Navy to produce its own design (incorporating the "best" features of the individual shipbuilder designs which the Navy now "owns"). While the Navy is able to exercise control over the design, the shipbuilders are also relatively free to innovate and incorporate producibility considerations which may be unique to their facilities. Each party therefore has a feeling of "ownership" of the design, and this approach has many advantages to offer.

A more radical approach is to turn the design totally over to industry with essentially no Navy control or oversight. In essence, this is the ultimate "performance spec" approach. A phased competition takes place with the number of competitors successively reduced until one ultimately emerges as the winner. Under this concept, industry is encouraged to innovate to the maximum extent possible, and (in some quarters) this is perceived as leading to major cost savings with no reduction in warfighting capabilities. However, when competing designs are produced by industry, the prohibition against ANY Navy involvement (for business reasons) has the potential for design deficiencies to be introduced. There is the potential that, in order to reduce acquisition costs, less attention will be paid to ship attributes such as reliability and maintainability, which are

difficult to quantify in a performance specification. NAVSEA will then be faced with correcting problems identified by INSURV and the Fleet.

Finally, there is a procurement strategy called the "two step", which has been frequently employed for the design and construction (or conversion) of relatively non-complex ships. Interested shipbuilders respond to a Circular of Requirements with their own designs and also build proposals (not paid for). The lowest bidder who satisfies all requirements is awarded the detail design and construction contract. This approach is best suited for cases where the technical risk is low. It is frequently employed to free NAVSEA design personnel to work on more complex warships. Another argument which is frequently voiced is that only industry can produce a "commercial design". Regardless, this approach motivates industry to incorporate cost savings, since the construction contract will be awarded to the lowest bidder whose proposal meets the Navy's stated requirements.

As discussed above, the Navy employs numerous approaches to involve the shipbuilder in the design process: everything ranging from the shipbuilder looking over the shoulder of the Navy ship designers to industry actually doing the designs with minimal Navy oversight. Our goal - cheaper and better ships - can and has been realized, and it seems clear that shipbuilder involvement will continue to be the accepted way of doing business. But the number of potential options is high, and the degree and the method of involvement which is "best" for any specific ship acquisition must be decided on a case basis.

Degree of Contract Design Definition

This issue also relates to the apparent contradiction between the National Research Council (NRC) study recommendation that the contract design baseline be firmer and the Acquisition Streamlining Initiative's injunctions whose collective

thrust is: specify less, take more risk, give industry more room to innovate and thus reduce cost. One of the implications of the zone-oriented ship construction approach is that ship design definition must be done earlier and more thoroughly. It must also be integrated with the ship production process. This is what led to the NRC recommendations to incorporate production considerations in the preliminary and contract design phases, reflect lead and follow yards' inputs in the contract design, e.g. facilities, suppliers and production methods, and produce a firmer design baseline at the end of CD. The NRC recommended that more emphasis be placed on system design and equipment selection in CD and less emphasis on structural detailing and space arrangements. Also, that the number of contract (non-deviation) drawings be minimized.

These NRC recommendations are generally endorsed and in fact are consistent with other recent events. One of the conclusions of an extensive study of naval ship weight growth during design and construction, which was completed a year or so ago, was that the distributive systems were the area where most unanticipated weight growth occurred and that more emphasis must be put on earlier design definition for these systems, i.e. during CD. We expect that, with the aid of advanced computer-based analysis and graphics tools, more distributive system design will be done during the CD phase in the future. Of course, there is no point to such effort if the lead shipbuilder is not tasked to build upon the system definitions established during CD rather than starting from scratch. In other words, when the desired definitions are established in CD, they must be further developed during the detail design phase, i.e. they must be specified in the completed CD package. This additional specification detail would be reasonably consistent with the acquisition streamlining injunctions only if the acquisition strategy followed were such that the prospective lead and follow shipbuilders actively participated in the CD effort. Only in that way could

the shipbuilders effectively influence the distributive systems' designs from a producibility standpoint. The DDG-51 acquisition strategy is an example of this approach.

6. Conclusions

This paper has focused on the interface between naval ship design and production and on current events, topics, initiatives and issues related thereto. Interest in this interface is at a peak these days primarily for two reasons. First, it is widely recognized that productivity improvements and hence ship cost reductions are dependent to a considerable degree on decisions made during design, not just in the detail design phase but also in earlier phases. Second, it is recognized that increasing threats make it essential that our new ships be fully effective, which means that they must be operable, reliable, maintainable and survivable as well as possess the desired mission capability. A necessary prerequisite is that a ship design reflecting these attributes be developed and reviewed by capable and experienced engineers prior to production.

Based on the information in the paper and its references, the authors' conclusions are:

- o Navy engineers involved in ship design and acquisition must be educated in zone-oriented ship construction technology. Formal training is necessary as well as the informal , on-the-job variety (NRC recommendation), This must be done promptly. The Ship Production Committee should take the lead in organizing appropriate curricula for executives, mid-level managers and working level designers and engineers.

- o Navy and industry must collaborate in developing computerized approaches to ship design, construction, life cycle support and management, including data transfer techniques (NRC recommendation). Efforts to this end are underway.

- o Means must be developed to incorporate production considerations in the preliminary and contract design phases. Educating Navy engineers and involving shipbuilders in these phases (at least in contract design) will go a long way. The development of producibility and manufacturing cost design guides to aid preliminary and contract design teams to develop more producible and cost effective designs is also needed (NRC recommendation The Ship Production Committee should also take the lead in this area.

- o The best approach for each of the three issues discussed in the preceding section is dependent on the specifics of particular situations:

  - Specifications tiering can be reduced and performance emphasized. Certainly the development of National Shipbuilding Standards with emphasis on commerciality should be accelerated. However, we cannot afford to suddenly abandon the Gen Specs and it's myriad, hard earned, lessons learned.

  - Many options are available for involving shipbuilders in contract design and even earlier. The best choice is dependent upon many factors as applicable to each specific case. As Navy ship designers we believe that for complex ships (including warships, amphibious, mine and MLSF ships which steam with the Battle Group) the best approach is generally

a Navy design effort in which two, or at most three, competitively selected shipbuilders actively participate as design team members during contract design. The competition for lead ship award should be restricted to these active participants. We have seen no hard evidence that shipbuilder involvement in the preliminary design phase is essential. Design guides should be sufficient to incorporate producibility considerations at this stage of design. For relatively simple ships, a shipbuilder design approach is generally best, either a phased, funded design competition or a Z-step procedure for the simplest cases.

- There are good arguments for increasing the level of detail addressed in contract design, specifically in the distributive systems. The need for better weight estimates and the requirements of zone-oriented construction. are both pushing us in that direction. Advanced computer-aided design tools to define and analyze these systems, when available, will enable us to accomplish this. We expect that within five years, distributive systems will be routinely designed in the CD phase.

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EXPANDED PLANNING YARD CONCEPT & CONFIGURATION ACCOUNTING
OR
IMPROVING NAVY SHIP ENGINEERING

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ABSTRACT

For several years the Navy has been methodically improving its organization and procedures for ship engineering. These improvements have resulted in an expanded role for the planning yard. The planning yard's two primary functions are ship alteration engineering and configuration identification. Responsibilities have been clearly defined and more discipline has been incorporated into the process for both of these functions. These improvements are in the early stages of implementation and detailed procedures will continue to evolve.

Requirements for ship acquisition programs have been refined to reflect these improvements.

We have learned that there is a need for clearly assigned responsibility in engineering, that configuration identification must be an integral part of engineering, and that logistics support must be an integral part of engineering.

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EXPANDED PLANNING YARD CONCEPT & CONFIGURATION ACCOUNTING

OR

IMPROVING NAVY SHIP ENGINEERING

For several years the Navy has been systematically analyzing problems with our ship engineering and improving the Navy's organization and processes for ship engineering. This paper briefly discusses the Navy organization for ship engineering and some of the major initiatives to improve ship enginering. These initiatives have led to an expanded role for the planning yard in supporting, maintaining, and modernizing Navy ships. The paper focuses on the two primary functions of the planning yard, ship alteration engineering and ship configuration identification.

THE NAVY'S ORGANIZATION FOR SHIP ENGINEERING'

The Navy has a matrix organization for ship engineering; with engineering as one axis of the matrix and management as the other. Engineering activities consist of life-cycle-managers (LCMs), in-service engineering agents (ISEAs), and planning yards. Management activities consist of the Office of the Chief of Naval Operations (OPNAV), ship logistics managers (SLMs), type commanders (TYCOMs), and ship acquisition project managers (SHAPMs). Figure 1 depicts this organization.

OPNAV sets broad policy and priorities for all activities in the Navy,

including ship maintenance, support, and modernization. These priorities are controlled primarily by funding allocations.

Ship logistics managers manage the support and modernization (alteration) of operating ships. Ship logistics managers are assigned responsibilities by ship class and ship type; that is, surface combatants, auxiliary and amphibious ships, submarines, and aircraft carriers. The ship logistics manager is the configuration manager for classes of ships assigned to him; he decides, based on OPNAV direction, what alterations will be installed in his ships.

Type commanders are fleet commands responsible for the maintenance of ships; they also schedule and fund the installation of some ship alterations.

Ship acquisition project managers manage the acquisition of new ships. Each ship acquisition project manager is responsible for the acquisition of assigned' classes of ships. The ship acquisition project manager is responsible for providing the initial logistic support required by the ship when it is first put into operation as well as developing logistic support that is not already in the Navy's standard inventory.

The life-cycle-manager is the headquarters engineer or organization responsible for the engineering and logistic support for a particular system or equipment throughout its life. For his system or equipment, he is responsible for research and development, new ship design and acquisition specifications, in-service engineering, configuration management, logistic support, and budget planning. The

life-cycle-manager provides the engineering for the ship logistics manager and the ship acquisition project manager. In addition, the life-cycle-manager will manage research and development and fleet improvement projects concerning his equipment. The life-cycle-manager is concerned with his system and equipment on all classes of ships in which it is used, while the ship logistics manager and ship acquisition project manager are concerned with only the classes of ships assigned to them.

The life-cycle-manager may be supported by an in-service engineering agent. The in-service engineering agent is a field activity assigned responsibility for day-to-day, hands-on engineering support to the fleet. This engineering support includes ensuring the technical adequacy of logistic support. Some in-service engineering agents also overhaul the equipment for which they are responsible. Most in-service engineering agents also perform the detailed engineering for , and direct the installation of alterations that are within the boundary of a single system or piece of equipment and the system or equipment external interfaces are not affected by the alteration. Examples of such alterations are: Ordnance Alterations (OrdAlts) for combat systems equipment, Field Changes for electronics equipment, and Machinery Alterations (MachAlts) for hull, mechanical, and electrical equipment. (Some Ordnance Alterations go well beyond the foregoing limitations.) These equipment oriented alterations often apply to several classes of ships.

The “planning yard” is actually the design division of a shipyard. There are 13 planning yards; 8 naval shipyards, 4 private shipyards,

and 1 supervisor of shipbuilding. Figure 2 lists planning yard assignments. The planning yard is responsible for engineering done on a class or ship basis. Basically, this involves ship alterations (ShipAlts) which install new equipment, remove equipment, modify systems, modify the ship's arrangements, etc. Planning yards are assigned responsibilities by ship class and generally each planning yard is assigned several classes of ships. The planning yard receives management direction from the ship-logistics manager and technical direction from the life-cycle-manager, In addition to ShipAlt design and engineering, the planning yard is responsible for maintaining selected record documentation (those drawings and manuals essential to the maintenance and operation of the ship and which must be maintained to accurately reflect the ship's configuation). For some classes of ships, the planning yard is also responsible for maintaining the Weapon Systems File, the Navy's single repository of ship component configuration information.

MAJOR INITIATIVES TO IMPROVE SHIP ENGINEERING

Starting in 1976 the Naval Sea Systems Command (NAVSEA) began a critical evaluation of its organization for ship engineering. This evaluation covered, at various times with various studies, military personnel (the Engineering Duty Officer community), civilian personnel (civilian engineers at NAVSEA), and the basic NAVSEA organization. This evaluation resulted in many significant changes in all three of these areas; military personnel, civilian personnel, and the NAVSEA organization. At the heart of all of these changes is the objective of improving our ship engineering; we are still following that course

today.

Starting in' 1980, the Navy established Senior Navy Steering Boards to critically examine several ship systems and equipment that were causing serious maintenance and readiness problems in fleet ships, These initiatives, and detailed investigations of the ShipAlt process, pointed out the need to improve the ShipAlt (Fleet Modernization Program) process and our logistic support. Without exception, every equipment that was experiencing serious problems in the fleet had serious logistic support deficiencies.

The basic objective in these initiatives has been to solve not only the specific problem identified in the fleet, but to identify and correct the faults, if any, in the Navy's "system", policy, and procedures for supporting, maintaining, and modernizing ships. In general, this is a complex process involving fundamental changes in several different commands in the Navy. The basic approach has been to analyze the problem, determine a solution, execute a Pilot Project, evaluate the pilot project, make corrections and implement the solution Navy-wide.

Improvements in the Ship Alteration Process

Significant improvements have been-made in the ShipAlt process in the last three years. Among these improvements are: clearly assigned responsibility and accountability for ShipAlt engineering, increased technical discipline throughout the process, clear documentation of the process, increased emphasis on logistic support, and increased emphasis on the identification and procurement of ShipAlt installation

material,

The basic ShipAlt process includes three phases of engineering development; ShipAlt Proposal (SAP), ShipAlt Record (SAR), and ShipAlt Installation Drawings (SIDs). Figure 3 illustrates the ShipAlt process. ShipAlts are designed and installed on a ship class basis; that is a single ShipAlt applies to all of the ships of a single class. The ShipAlt Proposal is usually prepared by the headquarters life-cycle-manager, It includes a level of detail typical of a conceptual design and it may identify some early material and logistic support requirements. The ShipAlt Proposal is the basis upon which the ship logistics manager's change control board decides whether or not to approve the alteration.

Once the ShipAlt Proposal is approved, the ship logistics manager tasks the planning yard to prepare the ShipAlt Record. The ShipAlt Record increases the level of detail of the ShipAlt Proposal and verifies the ShipAlt Proposal. The ShipAlt Record is important in that it identifies long-lead material for the ShipAlt installation and it identifies the logistic support required for the ShipAlt. Without a good ShipAlt Record, the early installations of the ShipAlt may have material problems and may not be properly supported. The ShipAlt Record is approved by the ship logistics manager and by the life-cycle-manager,

The ship logistics manager tasks the planning yard to prepare the ShipAlt Installation Drawings. The ShipAlt Record must be approved before drawings can be issued. The planning yard performs all of the necessary shipchecks and design work to produce a unique set of

ShipAlt Installation Drawings tailored to each individual ship of the class. To allow sufficient time for production planning, the ShipAlt drawings should be delivered to the installing shipyard twelve months before the start of the ship availability. Although every planning yard is not yet consistently delivering drawings twelve months before the start of the availability, every planning yard is steadily progressing towards this goal.

During the ship availability the planning yard provides an on-site representative to assist the installing activity with any technical problems that arise with the ShipAlt package. The planning yard is responsible for incorporating lessons. learned into the design for future installations of the ShipAlt.

The ship logistics manager is responsible for ensuring that all of the installation material and logistic support is provided for the ShipAlt. Of course, the ship logistics manager depends on the planning yard and the life-cycle-manager to identify the installation material and the' logistic support required.

Perhaps the most significant improvement in the ShipAlt process is the clear assignment of technical responsibility to the planning yard. In the past, the planning yard was only responsible for the "Basic Alteration Class Drawing" (BACD), the drawings for the first installation of the ShipAlt. The installing activity was responsible for shipchecking the ship and tailoring the alteration drawings to that specific ship by preparing "Supplementary' Alteration Drawings" (SADs). With such split responsibility there was little accountability for the ShipAlt engineering. Today, the planning. yard

is totally responsible for ShipAlt engineering, even during the installation of the alteration. To date, all planning yards readily accept this responsibility, although some installing shipyards are reluctant to depend on the planning yard for all of their ShipAlt design work. For practical reasons, the installing yard typically resolves minor technical problems, and the planning yard's on-site representative works through the installing yard's design organization in correcting any major technical problems. There have already been some instances of the planning yard sending a team of engineers to the installing shipyard to correct problems with a ShipAlt design. This process will foster the incorporation of lessons learned into the design of subsequent ShipAlt packages and will help improve the quality of ShipAlt engineering. (Note: For a few older- classes of ships only Basic Alteration Class Drawings are prepared by the planning yard and Supplementary Alteration Drawings are still prepared by the installing activity. Nevertheless, all of the other improvements in the ShipAlt process apply to these older classes of ships.)

Today there is considerably more discipline in the ShipAlt process than there was three years ago. There are technical specifications for ShipAlt Proposals, ShipAlt Records, and ShipAlt Installation Drawings (including Basic Alteration Class Drawings and Supplementary Alteration Drawings); there were no such specifications in the past. Technical problems and decisions are documented using "Liason Action Records" (LARs); there was no such documentation required in the past, Each step in the process, ShipAlt Proposal, ShipAlt Record, ShipAlt Installation Drawing, and the installation of the ShipAlt, is

clearly defined with specific milestones and minimum requirements established. Headquarters life-cycle-manager approval is required for every alteration; no life-cycle-manager involvement was required in the past. The life-cycle-manager may direct that he approve some or all of the ShipAlt Installation Drawings for complex alterations. Complex alterations require formal proofing of the installation and the design. And, last, the entire process has been clearly documented in the new Fleet Modernization Program (FMP) Manual.

For most ShipAlts today, the ship or a fleet activity supporting the ship must order some or all of the logistic support required for the alteration. In such cases it is not unusual for the support to arrive several months after the ship has been operating with the alteration installed. Due to the evidence of serious logistic support problems in the fleet, considerable emphasis is placed on logistic support in the ShipAlt process. The basic objective is to provide the logistic support to the ship concurrent with the installation of the alteration. The planning yard and the life-cycle-manager identify the requirements for new logistic support for the alteration and the ship logistics manager initiates and manages the actions necessary to deliver the logistic support. A variety of activities, including the life-cycle-manager, are responsible for actually providing the support, The Fleet Modernization Program Manual defines the who, what . when, and where for logistic support. Each activity responsible for procuring logistic support must certify the availability of the support and document deficiencies. The major emphasis today is on spare parts, preventive maintenance, technical documentation (drawings and technical manuals), and crew training. The process for providing

logistic support for alterations is still being refined.

The last major initiative in improving the ShipAlt process is the identification and procurement of alteration installation material. As with logistic support, the planning yard and the life-cycle-manager are responsible for identifying the material and the ship logistics manager is responsible for initiating action and managing the procurement of the material. The life-cycle-manager may identify and play an active role in the procurement of some special items. Plans to improve the material aspects of the ShipAlt process are still evolving.

Today most classes of ships have been included in the improved ShipAlt ("expanded planning yard") process described above for about two years. All new ships will be included in this process. Every planning yard has accepted these responsibilities and is steadily moving towards the goals set by the improved process. The ship logistics managers are working towards managing the ShipAlt process to meet these goals. Life-cycle-managers review and approve every ShipAlt Proposal and ShipAlt Record. And, OPNAV has provided the funding to do a better job of engineering ShipAlts,

NAVSEA headquarters closely monitors each yard's performance and the working of the ShipAlt process. Formal audits are conducted on selected ShipAlts and regular status meetings are held both at headquarters and with the planning yards. Follow-up action is taken to correct problems at a particular planning yard and to correct systemic problems with the new ShipAlt process.

Improvements in Ship Configuration Identification

One of the root causes of logistic support problems is the lack of complete, accurate configuration information for Navy ships and ship systems. Configuration information is the description of what systems, equipment, components, etc. are on the ship. A configuration item is any item:

1, that requires any type of logistic support, or
2. for which configuration data is needed to operate, maintain, or support the ship.

A configuration item may be at any level from the ship itself down through the piece-part level if necessary. Even a squadron or group of ships may be considered a configuration item. A configuration item may be included just for the purpose of completely defining the configuration of the ship or a system.

Configuration information is needed by logistic support activities that provide logistic support to the ship; they must know what they are supporting. Maintenance activities, such as tenders and shipyards, need configuration information to plan and execute maintenance. The personnel system needs configuration information to determine the number of crew, and their required qualifications, to man the ship. Life-cycle-managers and in-service engineering activities need configuration information so that they know where their equipment is installed and the characteristics and alteration status of each installation, Planning yards and in-service engineering agents need configuration information to design and

engineer alterations.

The "Weapon Systems File" is a central computer data base of ship configuration information. For 15 years it has been the Navy's single, authoritative source of information for ship configuration, Unfortunately, the Navy's engineering community neglected the Weapon Systems File and the Weapon Systems File structure did not satisfy the needs of many users. For example, it was very difficult to enter a configuration item in the file if the item did not have identified supply support, yet there are many items that require maintenance that do not have identified supply support. Configuration information is in Selected Record Drawings and other technical documentation; there was no attempt to reconcile the Weapon Systems File with the drawings and documentation.

There were two other fundamental problems with the Navy's system for ship configuration identification. First, there was no clearly assigned responsibility and accountability. Many activities could add, change, or delete data in the Weapon Systems File with no one having overall responsibility for the File for a ship. Several activities were responsible for processing data, no one was responsible for the accuracy and completeness of the File at all times. Second , the configuration status accounting functions were independent of the rest of the configuration management functions. The Ship Equipment Configuration Accounting System (SECAS), which maintained the Weapon Systems File, was independent of the ship logistics manager's configuration control and the planning yard's and in-service engineering agent's alteration engineering.

Due to the recognition that many of our “technical” problems are actually caused, or exacerbated, by inadequate logistic support, and the recognition that adequate logistic support and cost effective maintenance depends on good configuration information, the Navy’s engineering community has finally taken a sincere interest in ship configuration. The results of this interest are the development and implementation of the “Ships Configuration and Logistics Support Control Process”, the redesign of the Weapon Systems File, and improvements in Selected Record Drawings. The objectives of the Ship Configuration and Logistics Support Control Process are:

a. establish and maintain, with a high level of confidence, accurate configuration and associated technical and logistic support information for critical systems in ships, and

b. define and implement the system, procedures, and responsibilities to accomplish this objective.

The actions necessary to meet the foregoing objectives and solve the problems mentioned above are:

1. Clearly assign responsibility and accountability for the accuracy and completeness of information in the Weapon Systems File to a single <u>engineering</u> activity.

2. Structure the Weapon Systems File based on the functional configuration of the ship.

3. Correlate logistic support information with the configuration information in the Weapon Systems File.

4. Define procedures and assign responsibilities for reporting changes in a ship's configuration or logistics support.

5. Define responsibilites for correcting discrepancies in a ship's configuration and deficiencies in a ship's logistics support,

Each of these actions is discussed further in the following paragraphs.

It was decided to assign responsibility for the information in the Weapon Systems File based on technical responsibility for the equipment aboard the ship. That is, the activity responsible for the engineering for the equipment would be responsible for the configuration information for their equipment. Since the planning yard has overall responsibility for the engineering for a class of ships, the planning yard is assigned overall responsibility for the Weapon System File for assigned classes of ships. The in-service engineering agents provide configuration and logistic support information to the planning yard in establishing the File for a ship and in maintaining the File as the ship's configuration or logistics support is changed. The planning yard is responsible for hull, mechanical, and electrical equipment configuration information and for the overall File. In addition, any activity that installs an alteration, or changes a ship's configuration during repairs, is responsible for reporting the 'change to the planning yard. Only the planning yard is authorized to change information in the Weapon Systems File.

Assigning the responsibility for configuration information to these engineering organizations enhances the integration of configuration accounting with the rest of the configuration management functions. The planning yard is responsible for the engineering for significant configuration changes, i.e. ShipAlts, and monitors their installation. The in-service engineering agents generally perform the engineering for specific equipment configuration changes, i.e. Ordnance Alterations, Field Changes, and Machinery Alterations, and directs their installation. Installing activities actually make the change. Including configuration identification responsibilities with engineering responsibilities will lead to improved configuration information with reduced cost. For example , rather than sending an independent team to shipcheck the ship's configuration, the engineering activity can combine alteration design shipchecks with configuration shipchecks done by technician and engineers that know the system they are checking.

A very important concept is the functional structure of information in the Weapon Systems File. A good, functional hierarchical structure is fundamental to presenting useful information. The old Weapon Systems File was not rigorously structured based on the design of the ship systems. For example, the components that made up the "firemain" in the Weapon Systems File might not be at all related to the components included in the "firemain" in drawings, technical manuals, and other documentation aboard the ship. As a result, it was often very difficult to find an item in the File and to be sure that the correct item was identified. In addition, it was very difficult to see that

there is a one-to-one correlation between the actual shipboard systems and the File. This problem was amplified by the use of only "commodity nomenclature", such as, "valve, globe, 4 inch, 600 psi" in the File.

The functional hierarchy is represented by two pieces of information, the "equipment functional description" and the "functional group code". The equipment functional description is the English language name typically used by operating and maintenance personnel; for example, "fuel oil service pump no. 1", or "air conditioning plant no. 3 motor controller". The functional group code is a number assigned to each item so that a computer. (or a person) can identify the system-subsystem-equipment-component relationships and present the information to the user accordingly. There is a one-to-one correspondence between the equipment functional description and the -functional group code. Every configuration item is assigned a unique equipment functional description and a corresponding unique functional group code.

The Navy ship design community has used a standard functional hierarchy called "Ship Work Breakdown Structure (SWBS)" for many years. This structure is well known to all Navy ship designers: Group 100 is hull structures, Group 200 is propulsion, Group 300 is electrical power generation and distribution, etc. This long-standing system has recently been extended to lower levels of indenture to fully meet the needs of configuration identification. This "Expanded Ship Work Breakdown Structure/Functional Group Code" has been promulgated in the new NAVSEA instruction 4790.1A, "Expanded Ship Work

Breakdown Structure (ESWBS) for All Ships/Ship Systems", The instruction defines the procedures and requirements to develop a logical configuration definition of the ship starting with the design of the ship, defined in detail during the construction of the ship, and maintained during the life of the ship. This functional identification is tremendously important because it is the single link that ties the ship's functional configuration (the ship itself), which is what the operator and maintainer recognizes, to the logistics support and technical information for that configuration.

Most of us recognize "ILS" as "Integrated Logistics Support". Unfortunately, today's Navy logistic support elements are more "Independent" than "Integrated". The shipboard sailor or shipyard worker has no single source he can depend on to identify all of the support for an item. (Without. the foregoing functional structure for information, he may not be able to identify any of the support for an item!) Another major element of the Ship's Configuration and Logistics Support Control Process is identifying all of the major logistic support required for each item and correlating that with the configuration information. Today we are focusing on just spare parts, technical manuals, drawings, preventive maintenance, test equipment, and eventually training. However, we are building the capability to identify virtually any piece of technical or logistic support information to the configuration. This provides the user, the operator or maintainer, with the necessary logistic support information in one document, or computer file. This information is stored in a central file, accessible to all users, so that once the research is done to identify the technical and logistics information

it is not necessary for other users to repeat the same research. Note, that the object is to just <u>identify</u> the logistic support. That is, the drawing number or technical manual number would be identified; the File would not actually contain the drawing or technical manual itself,

Establishing a properly structured, accurate File is only part of the process. Equally important are the procedures and responsibilities for establishing and maintaining the information in the File. These two pieces of the overall process must be designed to work together; the central computer file and processing (the Weapon Systems File) must be compatible with the management system for maintaining the data in the file. The best automatic data processing system we can design cannot make up for an inadequate management system for establishing and maintaining that data. The Navy has defined this process in directives for the Ship's Configuration and Logistics Support Control Process. In the near-term we are making the necessary changes to the Weapon Systems File computer programs to accomodate the Ship's Configuration and Logistics Support Control Process. For the long-term we are completely redesigning the Weapon Systems File computer software so that it is fully compatible with the new concepts and process for maintaining ship configuration and logistic support information.

The final significant feature of the Ship's Configuration and Logistics Support Control Process is correcting the problems discovered during the process. When the planning yard discovers either a configuration discrepancy or a logistic support deficiency (logistic support not

available in the Navy system), he informs the ship logistics manager who initiates action to correct the deficiency.

Ship configuration information is also represented in “Selected Record Drawings”. Selected Record Drawings are typically systems drawings and ship arrangement drawings that are essential to the modernization, maintenance, and operation of the ship. Selected Record Drawings are maintained current throughout the life of the ship. Improvements have also been made in the Selected Record Drawing process. In the past, planning yards had custody of the drawings, overhaul shipyards were responsible for updating the drawings to reflect alterations installed by the shipyard, and the ship’s crew was responsible for marking up the drawings to reflect changes or corrections between overhauls. This split responsibility resulted in inaccurate Selected Record Drawings. In addition, very few ship systems had been designated for Selected Record Drawing coverage on surface ships, These problems are now being corrected by expanding the list of Selected Record Drawings for surface ships to cover all critical ship systems and by clearly assigning responsibility for the Drawings to the planning yard. (Submarines already had a comprehensive list of Selected Record Drawings).

These initiatives to improve ship configuration identification are still in the early stages of implementation. The pilot project for the Ship Configuration and Logistics Support Control Process is the FFG 7 Class with Long Beach Naval Shipyard as the planning yard. Restructuring the Weapon Systems File to reflect a true functional hierarchy, identifying all of the key logistic support, and

correlating the logistic support to the configuration has turned out to be a formidable task. This effort will be completed this-fall on the first FFG 7 Class ship. It includes updating the Selected Record Drawings, and ensuring that the Drawings are consistent with the Weapon' Systems File.

The Ships Configuration and Logistics Support Control Process has been documented in a draft technical specification and several other planning yards have been tasked to begin implementing the Process on selected classes of ships. New classes of ships will follow the new Process when those ships are commissioned. In the meantime, most existing classes of ships are still under the Ship Equipment Configuration Accounting System (the system and procedures used to maintain the Weapon Systems File before these improvements) using the old Weapon Systems File structure.

OPNAV has budgeted and allocated the funds for the planning yards to prepare the additional, new Selected Record Drawings for many classes of ships over the next several years. This effort just started in 1985.

Last, the redesign of the Weapon Systems File for the long-term has just begun. The Navy's engineering, maintenance, and logistics. support communities are working together to prepare a requirements statement for the development of new computer software.

Improvements in New Ship Acquisition

We are learning the hard way how difficult it is to correct serious

deficiencies in configuration and logistic support identification and in the actual logistic support for ships that have been in service for several years. As a result the Navy is incorporating the lessons learned from these efforts into new ship acquisition requirements, Past shipbuilding programs were not required to deliver a good, functionally structured configuration and logistic support data base. Some ship acquisition programs did prepare such a data base in the past. However, the Navy had no way to store, maintain, and disseminate the information in such a data base. Future shipbuilding programs will be required to provide a validated data base of configuration and logistic support information in the format required by operational ships. That data base will establish the new Weapon Systems File for the ship.

In addition, we are defining the planning yard's role and adding more discipline to the life-cycle-manager's role in new ship acquisition. Life-cycle-managers are placing more emphasis on new designs, major new designs are being done primarily "in-house" by collocated design teams which include design contractor and potential shipbuilder support. And, life-cycle-managers are taking a more rigorous approach to identifying requirements for the review and approval of the shipbuilder's drawings and other products. The result is more detailed life-cycle-manager review of more shipbuilder products.

In the past, the planning yard did not participate in the ship acquisition and may not have been designated until after the ship was delivered. The planning yard is now designated during the ship design phase. The planning yard participates in the Contract Design and in

the ship acquisition process. The planning yard's involvement is primarily in configuration identification and in the documentation, such as Selected Record Drawings, needed to maintain and modernize the ship.

This emphasis on new construction requirements is important because these products are essential to effectively maintaining, supporting, and modernizing ships at a minimum cost. By providing a clearly defined, user oriented index of all necessary information, exercising the discipline described here for configuration and logistic support identification may actually lead to reductions in shipbuilding costs as well.

SUMMARY

The important lessons learned from these experiences are:

The need for clearly assigned responsibility and accountability in engineering;

The need for including configuration identification as an integral part of engineering.

The need for including logistic support as an integral part of engineering.

In an organization as large as the U.S. Navy it is easy to diversify responsibilities to the point that no one is really responsible for the end product. Unfortunately, this happened to our ship engineering. The Navy is now well along the course for correcting

this problem. Responsibilities have been clearly defined and accountability clearly assigned for much of our ship engineering. The engineering process for ShipAlts has been defined so that the responsible organizations have the authority and are in a position to exercise their responsibility. This concept is much more than just being able to identify who caused a problem. The most important benefit of clearly assigned responsibility and accountability is the sense of ownership and pride in the product that is nurtured in the individual engineer and in his organization. We are seeing this today in our planning yards. For the first time in years the planning yard engineers that work on a ShipAlt design can say, “This is my design,” They are taking pride in their work and showing a sincere interest in doing a good job of engineering) following up on the installation, and improving their design. The planning yards are developing a real sense of ownership for their classes of ships and are rapidly becoming the Navy’s experts for their ships, No management or quality assurance system can do as much to assure a quality engineering product as this sense of ownership.

The need for good configuration information to support, maintain, and modernize our ships is obvious. Each of these areas suffers with poor performance and unnecessary expense due to the lack of good configuration information. To be useful to the wide variety of activities that need configuration information, and to maintain a good quality match between the configuration information and the actual ship, the configuration information must be functionally structured. In addition, all of the configuration information) such as drawings, systems manuals, training manuals, and the Weapon Systems File, must

be consistent. The engineer responsible for the design and maintenance of a system or equipment must define its configuration, That engineer fully understands his system; no one else can define its configuration as well as he can. This configuration definition must start with the system design and be maintained, as part of the engineering process, throughout the life of the system. Once defined, that configuration then drives the entire logistic support, maintenance, and modernization process; it should drive the new construction process as well. Rigorously defining the configuration, in functional terms that all users clearly understand, provides the link between the ship itself and all of the technical and logistics support information for the ship. By providing a clearly defined, user oriented index to all of the information needed, exercising this process can lead to significant savings in ship construction as well as ship maintenance, support, and modernization.

Our configuration problems also reinforced the lesson on responsibilities. Without clearly defined responsibilities and a disciplined process for maintaining configuration information, extensive computer verifications and independent audits, etc. failed to maintain a complete, accurate, useful configuration file.

Perhaps the solution that is the most difficult to implement is making logistic support an integral part of engineering. The Navy has a very complex system for providing logistic support to ships. As a result, the sailor is left with a very complex job to find all of the support he needs to operate and maintan his equipment. Each logistics support element (technical manuals, supply supports training, preventive

maintenance, etc.) is provided by separate organizations that function independently of one another. The only place that these elements are brought together (besides at the user at the end of the chain) is at the engineer at the beginning of the chain. The engineer must identify the need for logistic support; he must see that each element of logistic support is technically correct; and he must see that the various elements of logistic support are compatible (for example, that the supply system provides the parts needed for the preventive maintanance and that the technical manual explains how to do that preventive maintenance). No one else has the thorough understanding of the equipment necessary to correctly structure the logistic support. Without the engineer's involvement, all of the paper analyses and quality assurance plans are doomed to producing a less than adequate end product.

In most of our engineering organizations today, logistic support is not even an integral part of the organization or of the engineer's responsibilities. The logistic support is often left up to a separate "allowance" section or to logisticians that perform all of the technical work associated with the logistic support. Our organizations must change so that the technical work necessary for good logistic support is a clearly defined engineering responsibility. We will always need specialists in each logistics support area. However, these specialists must be a small group that works closely with, and relies upon, the designers to produce a good logistic support package. We are beginning to see this happen in some of our planning yards today and in some of cur life-cycle-management organizations.

The Navy's efforts to improve ship engineering are just beginning, After years of correcting organizational and personnel problems and analyzing procedural and systemic problems, we are at the beginning stages of defining, evaluating) and implementing the fundamental changes to the Navy's system that are necessary to improve our ship engineering. Making such substantial, fundamental changes to such a large, complex organization must be approached with care and takes time. The planning yard is a key organization in the Navy's ship engineering process and the focal point of many of these improvements. We are finally at the point where we can begin to see some results from these systemic improvements. NAVSEA will continue to closely evaluate our performance in ship engineering, including configuration management and logistic support, and make needed improvements in our organizations, systems, and procedures. These improvements in ship engineering undoubtedly will result in much needed improvements in fleet maintenance, support, and modernization. We still have a long way to go.

FIGURE 1
THE NAVY'S ORGANIZATION FOR SHIP ENGINEERING

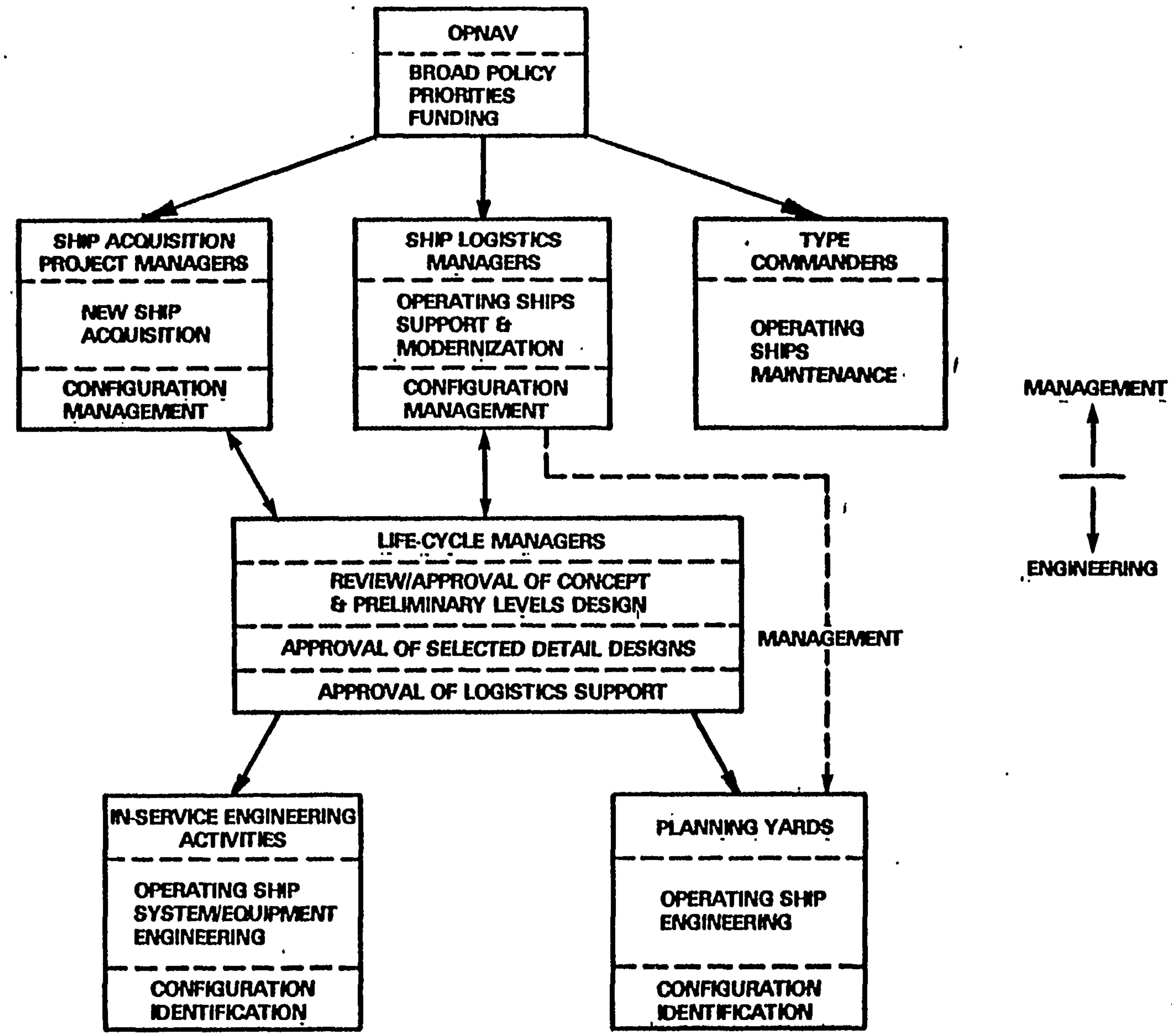
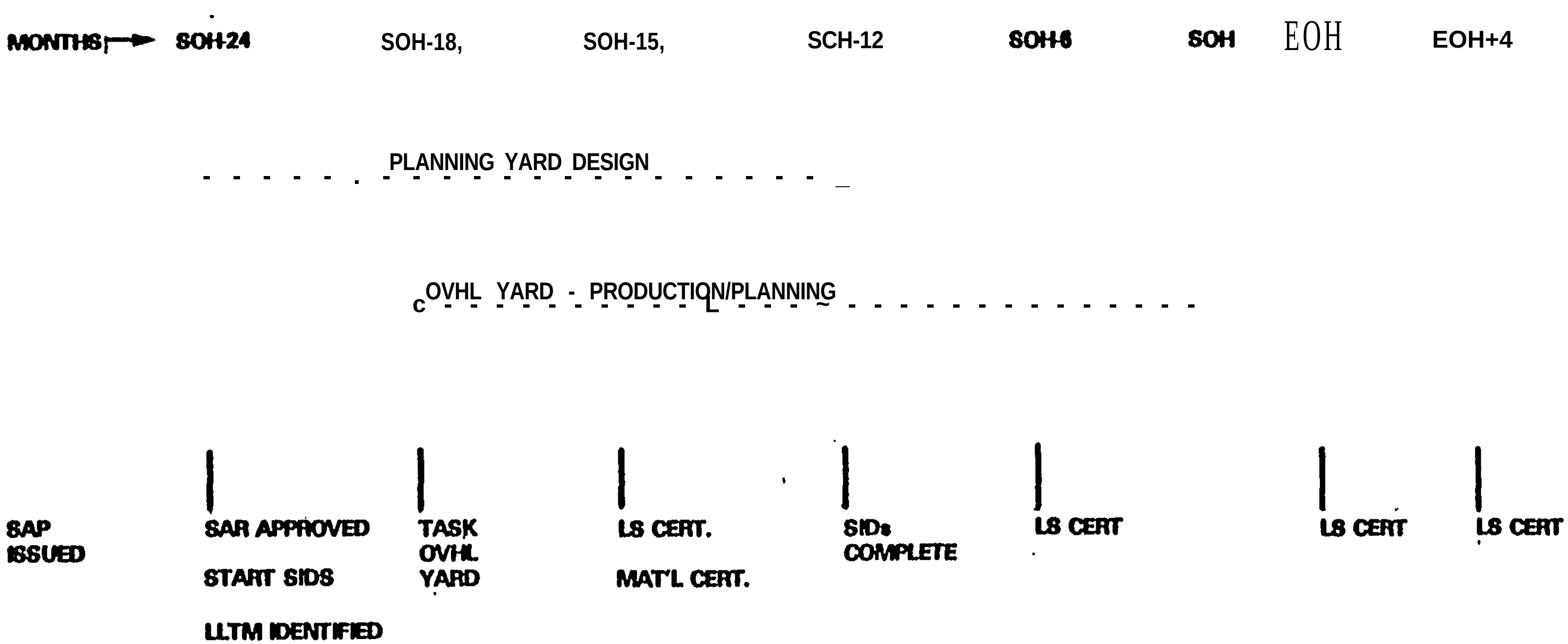


FIGURE 2

PLANNING YARD ASSIGNMENTS

o NAVSHIPYARD PORTSMOUTH	SSN 594; SSN 637
o NAVSHIPYARD PHILADELPHIA	LCC, LPN, DDG 2
o NAVSHIPYARD NORFOLK	CGN, CVN 68 (LANTFLT), DDG ‘51
o NAVSHIPYARD CHARLESTON	AD, AS, AR, MSO, MSH, DRYDOCKS
o NAVSHIPYARD PUGET SOUND	CVN 65, CG, CV, (PACFLT), UNREP SHIPS
o NAVSHIPYARD MARE ISLAND	ASR 21, DSV, DSRV
o NAVSHIPYARD LONG BEACH	BB, LHA, FF1037, FF1040, FFG 1, FFG 7
o NAVSHIPYARD PEARL HARBOR	FF 1052, ARS
o SUPSHIP BOSTON	LKA, LPD, LSD, LST
o ELECTRIC BOAT	SSBN’S + UNIQUE SSN’S
o NEWPORT NEWS	**SSN 688**
o INGALLS	**DD 963, DDG 993, CG 47**
o BOEING MARINE	PHM

FIGURE 3
SHIPALT PROCESS



SOH-START OF OVERHAUL
EOH- ENDoF OVERHAUL
SAP - SHIPALT PROPOSAL
SAR - SHPALT RECORD
SIDs - SHIPALT INSTALLATION DRAWINGS
LLTM - LONG-LEAD-TIME MATERIAL
OVHL- OVERHAUL
18 CERT - LOGISTICS SUPPORT CERTIFICATION OF AVAILABILITY
MAT'L CERT - MATERIAL: CERTIFICATION OF AVAILABILITY

LIST OF FIGURES

Comment by L.D. Chirillo

Re "Expanded Planning Yard Concept & Configuration Accounting"
by CAPT A.R. Karn & CDR E. Runnerstrom
NSRP 1985 Ship Production Symposium
12 September 1985

As a result of a series of NSRP projects, all major private shipyards in the U.S. are now adopting zone-oriented logic for constructing ships. The same logic has been successfully applied by the Puget Sound Naval Shipyard for ShipAlts and also for overhaul work. A pertinent paper is being presented during this Symposium.

As a consequence, some private shipyards have already started to abandon traditional functional organizations in favor of product organizations. In principal, their organizations will be similar to those employed by successful corporations such as Exxon and IBM. The singular feature of product organizations, is their unprecedented integration of design engineering and production engineering.

We have heard that because of the Expanded Planning Yard concept, at least one Navy yard will have to apply about 90% of its total design effort for projects to be undertaken in other yards. This seems to be at odds with the greater integration of design engineering and production engineering that many corporations, including CM, are now finding necessary for survival. In this respect, the Expanded Plan Yard concept seems to be a movement in the exact opposite direction from where research into modern organizational theory is leading us.

CAD/CAM DIRECTIONS FOR NAVY

By

CAPT. John F. Leahy

J. Christopher Ryan

Naval Sea Systems Command

CAD/CAM DIRECTIONS FOR NAVY

by: John F. Leahy III and J. Christopher Ryan

Brief Historical Review of navy CAD/CAM Projects

In the past two decades, the U.S. Navy has undertaken significant projects in the computer aided design, manufacturing, and service life support areas. A few of the those most related to the shipbuilding programs are listed in Table 1 along with the phase in the ship's life cycle they were primarily supporting.

TABLE 1
MAJOR NAVY CAD/CAM PROGRAMS

Title	Date	Emphasis Design	Build	Maintain
CASDAC	1967	X	X	
ISDS	1969	X		
CAEDOS	1981		X	X
CSD	1982	X		
MAN/TECH	1982		X	
NICADMM	1986	X	X	X

o CASDAC (Computer Aided Ship Design and Construction) was the grandaddy of them all, dating back to the late 60s when the Navy was designing and building its own ships.. The project's goal was to develop software for doing early stage design, through contract design, and detail design at the naval shipyards. They labored under the dual burdens of expensive hardware and relatively unfriendly software development environment, with clumsy. operating systems, occasional need for assembly language programming, and early compiler limitat ions. Never-the-less, many programs that are still with US. today began during that era, including: SHCP (Ship Hull Characteristic Program) ; SSDP (Ship Structural Design Program); HULDEF (Hull form Definition); and SDWE (Ship Design Weight Estimating). The state of CASDAC's progress by the early and mid 70s **is** well described in references [1] and [2]. The monument al CASDOS (Computer Aided Structural Detailing Of Ships) was developed under CASDAC's sponsorship and actually used to build 6 LCUs for the Army and for Saudi Arabia. Over half of CASDAC's efforts were oriented toward shipyard product ion software, including electrical wiring and fluid piping systems programs. In 1981, long after the end of new ship construction at the Navy yards, CASDAC was subdivided into two distinct programs, the CSD (Computer Supported Design) project, carrying on the ship design software development, and portions of the MANTECH (manufacturing and technology) program for advancing industry's efforts to improve shipbuilding productivitiy through automation and technology.

o ISDS (Integrated Ship Design System) was also part of the

overall CASDAC project but warrants special note because of it similarity to current efforts in the CSD project. The ISDS system wa supposed to be a cohesive set of computer programs for the design o Navy ships that was integrated through a common data base'[3]. A that time, commercial DBMSs (Data Ease Management System) were i their infancy and not oriented toward engineering (In fact, they stil aren' t with few exceptions). The ISDS Project thus also needed t develop its own DBMS, nicknamed COMRADE, along with the ship desig software and the graphics capabilities. AT that Juncture, the Nav was at the forefront of ADP technology and presented numerous paper- at the 1973 National Computer Conference [4,5,6]. Unfortunately, thi landmark system was ahead of its time in its demands on computer resources and performance. It also suffered from being developed in laboratory environment removed from the front line ship desig activities and the associated "NIH" (not invented here) attitude fra its supposed users. Its demise came after it had already tackled so of the most difficult technical problems of data base management an system architecture.

o CREDOS (Computer Aided Engineering and Documentation System) resulted from the need for a manufacturing-oriented system for Navy labs. The commercial CAD/CAM market was tapped in an attempt provide up to date "turnkey" CAM capability to support genera mechanical modelling/numerical control tape generation and som specialized production needs, such as for printed circuit boards. NW China Lake initiated the largest single purchase CAD/CAM equipmen in history , ultimately valued at almost $100M, for the benefit of al Navy labs and, subsequently, Navy shipyards. Computervision (CV won. the bid, delivering approximately 200 interactive graph i workstations over the period of 1982 to 1985. NAVSEA headquarters ha used some of the CV workstations an the DDG51 and SSN21 designs t explore their utility in the early phases of ship design engineering While CV provides powerful 3-D geometry modelling capability, it ability to support the analysis portion of naval ship engineering i minimal. Its greatest promise to engineering is as a part of a integrated system of modelling and analysis that the Navy mus develop. The CREDOS contract capacity has been exhausted mw and wil be replaced by a new CAD/CAM acquisition effort.

CSD (Computer Supported Design) is the continuation o CASDAC's early stage ship design software development effort. Forme in 1981, it has focused mare intently on two facets : developing working integrated system of ship design programs that are linked vi a common data base; and the transfer of computer sensible data to th private shipbuilders at the end of the Contract Design phase. In th current terminology, CSD has become oriented toward the development o the ship "product model" and "digital data transfer". This i discussed in greater detail in the rest of the paper. Figure 1 show the general time relationship of CSD, MAN/TECH and NICADMM programs.

0 NICADMM (Navy Integrated Computer Aided Desig Manufacturing and Maintenance system) is intended to be the, comm data base and interface system for the engineering related data t support the entire life cycle of a ship. This program is currently i the initial stages of format ion. A "cradle to grave" system

NICADMM would use the "product model" developed by CSD to initialize the data base and continue its expansion during construct ion and the ship's service life for long term support of ship alterations and modernizations. This program is noted as a key future direct for Navy and is presented in more detail later in the paper. Figure 2 shows the interfaces between NICADMM, the shaded areas, and other ship life cycle functions.

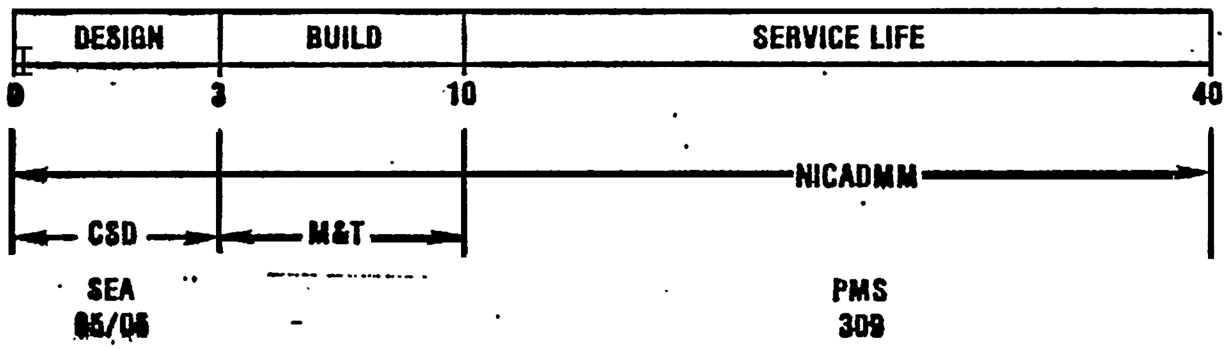


FIGURE 1. Time Relationship of CSD, MAN/TECH and NICADMM Programs

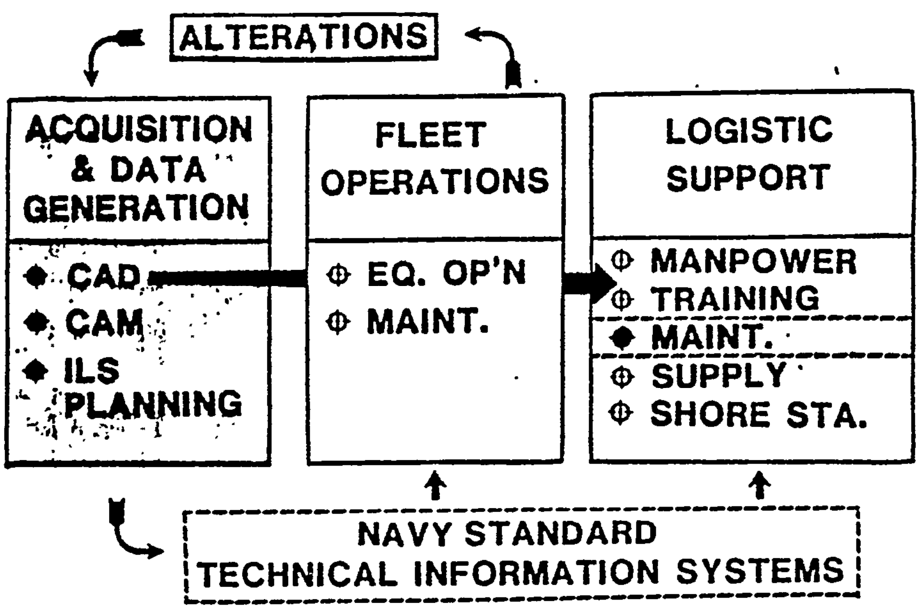


FIGURE 2. NICADMM Interfaces to Ship Life Cycle Functions

Recent Navy CAD/CAM Activities

Mr. Raber's presentation to you three years ago on this subject provided an good overview of the status of CSD [7]. Using that as the initial basis for this discussion, recent CAD/CAM efforts at NAVSEA have concentrated in four′ areas: development of an integrated ship engineering system; fostering digital data transfer for ship

Projects: and liaison with the marine industry.

Integrated CSD System. The CSD integrated system for ship design engineering is constructed of components common to virtually all such systems, namely: a central data base; a data base management system (DBMS); a system controller program, called SYSEX (System Executive); and ship design applications programs. Figure 3 provides an overview of the relationship of the CSD system components. Supporting these efforts are the implementation of software development standards anc initialization of a software toolbox for improving software development efficiency.

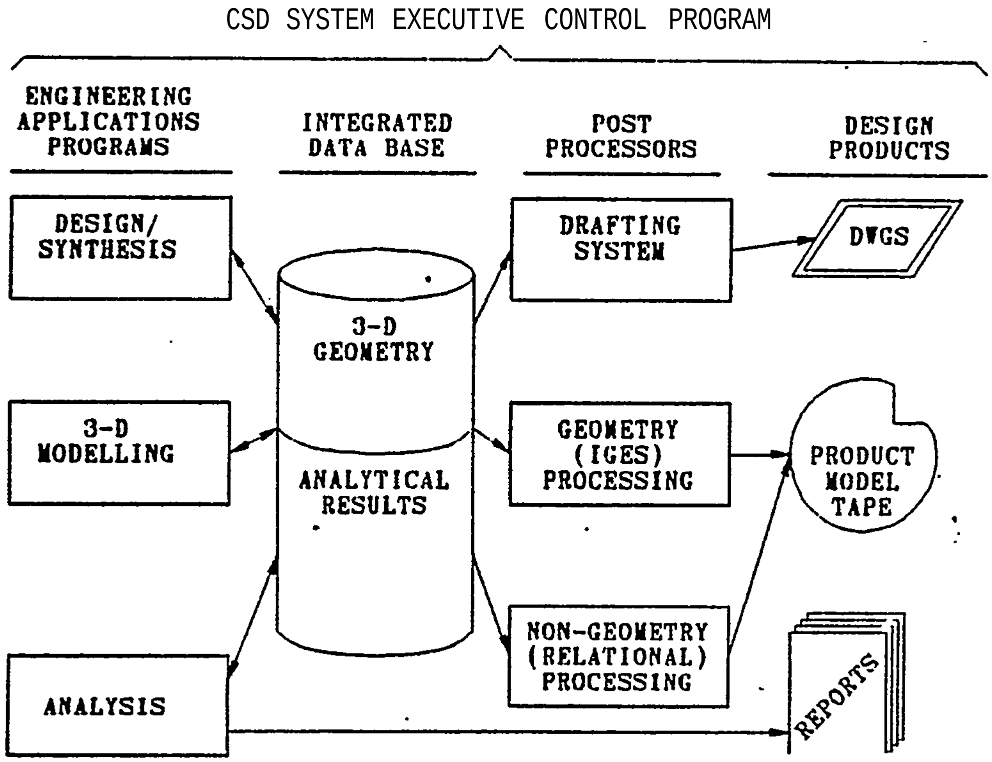


FIGURE 3. Integrated CSD System Components

Integrated Data Base The central data base far CSD is called the IDB (Integrated Data Base) and has been under intense development factor two years now. The central data base is the heart of the CSD system. It will contain both geometric information and analytical results about the ship, including all the data needed to produce the "product model" for later transfer to the shipbuilder. The IDB would additionally contain all data that needs to be exchanged between different engineering organizations and data for ship design project management. Among these, the definition of ship geometry has been the most time consuming and intractable portion of the IDE development. The current concept is to store surface definition information for the ship's hull and internal bulkheads, structural stiffener trace information, and simple bounding prism information for

equipment. Distributive systems, such as Piping and cabling, are not defined in the IDB. This limited sophistication of geometry definition is in line with the level of ship design engineering performed for most surface ship5 at NAVSEA but doe5 not provide a full S-D geometric representation for subsequent data transfer. It is not adequate for submarine or small ship work and provides limitations to growth as designs become more complex and detailed. As a result, we are now exploring other approaches to designing a data base adequate for a complete geometric definition of the ship.

Data Base Management Systems. Two years ago, the CSD project did a review of commercially available DBMSs in the interest of selecting one for the initial work on the IDB. It was clear that relational DBMSs had "arrived" and were the most desirable choice for our work since they required the least specialized support and provided the most flexibility for future changes as the data base design evolved. Table 2 itemizes many of the evaluation factors used in examining the various candidates.

TABLE 2
DBMS EVALUATION FACTORS

Ease of use
Application program interface (primarily FORTRAN)
Data type5 for engineering
Data structure
Efficiency
Flexibility.
Integrity
Security
Recoverability
Graphics capability
Report Generators
Data dictionary
Application generators
Screen capabilities
Utilities
Portability
Performance
Monitoring
Distributed data
Vendor support
Ease of implementation
cost

The most important factors were: cost; suitability to engineering usage; machine resource impacts; ability to implement it quickly; and availability to run on many different computers to foster data transfer. Least important were performance (speed of execution) and data security since: 1) unlike a DBMS for business purposes, engineering data is not handled as a series of "transactions" but rather in "batches" that closely parallel computer files in size and structure and 2) organizational boundaries are well defined and data access and control are relatively easy to define. On this basis,

Being's RIM (Relational Information Manager) was chosen. RIM is th outgrowth of the NASA and Navy sponsored IPAD project that has becom a commercial product [8].

RIM served well as the first DBMS for the IDB and also as a educational vehicle. It's strong points, yet to be duplicated by an other DBMS we have encountered, include specialized engineering dat types (matrices and floating point numbers) and low machine resourc requirements (although it requires large scratch files for sorting) It's weak points have become ever more important as the complexity o the IDB has grown, including: poor backup and recovery; single vie multi user write capability; unfriendly FORTRAN program interface and limited accessory features such as screen formatting and dat dictionary. The CSD project has also concluded that other forms o data transfer besides RIM to RIM on different machines are possible and more in line with the general trend toward development o interface standards. In this light, while RIM will still be supporte for the single user, a more well developed relational system wil likely be utilized, for CSD functions in the future.

system Executive (SySEX) Control Program. The current shi design environment requires the examination of a large number o alternative design features, many of them in simultaneous paralle efforts. For example, a single design project may have severa candidate hull forms, several general arrangement alternatives multiple main and auxiliary machinery options, and a variety of comba system configurations under investigation at one time. Eaci combination of these constitutes a variant of the baseline that ha some unique data associated with it. With computer based dat transfer, some means of identifying the specific ship variant i necessary. There is the additional need to tag the data with a "approval" status, giving the recipient of the information thr knowledge of its official standing in the design project. A trackin function is clearly required for each variant of the data base and currently, not conveniently provided by any commercial DBMS. The CS project thus initiated the development of the SYSEX control program t perform these parts of the data base administration function.

In using the CSD integrated system, the SYSEX program is thi gateway to all functions. The **series** of pictures in figure 4 outline the general flow of data and program executution while performing specific engineering design function using the IDB. First, th engineer requests SYSEX to extract data from the IDS and place it i< a local file. The engineer then runs his application program using th

extracted IDB data and other data, such as catalogs of information under the control of SYSEX which records the specific version of eat data file that was used during the run. Any portion of the program out put which is to be returned and. added to the IDS is also recorde by SYSEX. Each variant of the IDS for that ship project can have only one approval level: "private"; "proposed"; "released"; "approved" o "archived". This approach establishes a pedigree for each piece o data in the IDE and helps to insure consistency of the total shin dat base.

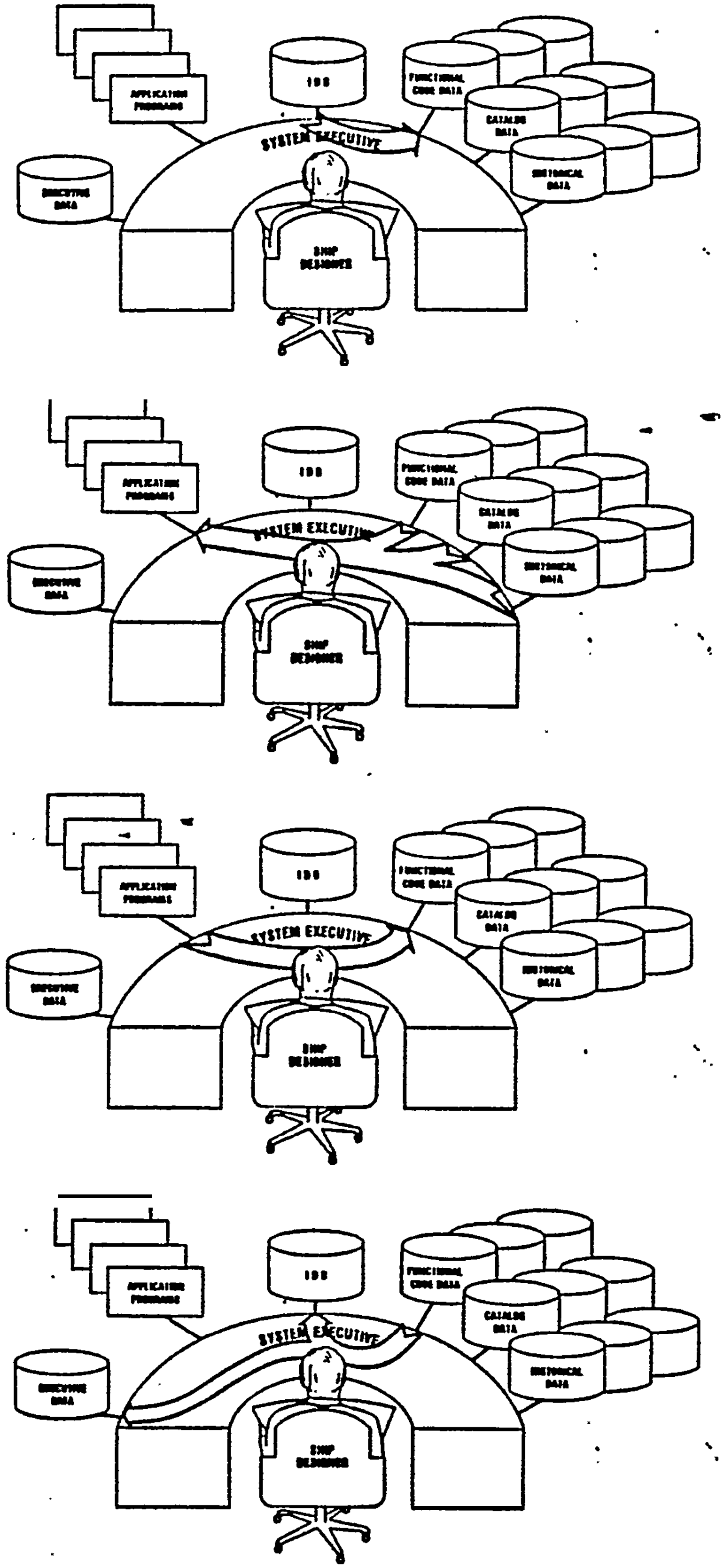


FIGURE 4. Operation of Integrated CSD Design System Under SYSEX

The SYSEX program is useful for keeping track of an individual's files a5 well as those for the whole CSD system and its use is encouraged for each engineering group. The second version of SYSEX will be operational this fall.

Ship Design Applications Programs. By far the largest part of the development of the CSD system to date has been centered on ship design applications programs. These are mostly unique to the marine industry and not readily available in the commercial market, although that picture is changing rapidly. Since the last report of reference [7], noteworthy project events have occurred in three categories: acquisition of commercial programs; new or improved in-house developed programs; and Computervision utilization. These are briefly described as follows:

o MOSES (Model Of a Shipboard Energy System) [9] . This program was developed in large part by David Taylor Ship Research and Development Center (DTNSRDC) to analyze the performance of shipboard energy systems for applications other than nuclear or oil-fired steam propulsion plants. The program is a simulation model that performs a complete thermodynamic analysis of a user-specified energy system. It offers considerable flexibility in analyzing a variety of propulsion, electrical, and auxiliary plant configurations through a component building block structure. Component subroutines that model the performance of shipboard equipment such as engines, boilers, generators and compressors are available from the program library. Component subroutines are selected and linked in the program to mode1 the desired machinery plant functional configurations. The operation of the defined shipboard energy system may then be simulated over a user-specified scenario of temperature, time and load profiles. The program output furnishes information on component operating characteristics and fuel demands, which allows evaluation of the total system performance. This program is most useful during the very earliest stages of ship feasibility studies when a very large number of alternative machinery plants need to be quickly assessed. It provides key fuel consumption values for input to the ship synthesis models, such as DD08 and ASSET [10,11].

o CLAM (Compartment Location and Arrangability Model) . This NAVSEA sponsored program is completing its first operational capability this fall and permits the rapid evaluation of combat system space arrangement feasibility. In the earliest design stages, the program uses combat system compartment boundary information and a preliminary list of electronic equipment to enable rapid, simulated 3-D evaluation of the equipment arrangement of the space. Specific criteria, such as allowable cable lengths and maintenance access clearance requirements, can be checked is real time. The main purpose of the program is to determine the feasibility of putting the combat system equipment in the proposed space allocations and estimating an overall figure of merit for alternative space configurations.

o GADS (General Arrangement Design System). Also coming on line this fall are major geometry modeling portions of the General Arrangements Design System for performing ship arrangement development

throughout Preliminary and Contract Design. This set of programs uses a user friendly inter-face and marine-oriented terminology to aid the engineer in interactively laying out the interior bulkheads and compartment boundaries for an entire ship. It builds on the hull form geometry data that can be generated several different way5 by other programs and transmitted via the IDB. GADS can keep track of area allocation by compartment and produce area/volume reports directly from it5 specialized data base. The GADS system is to be the source of a large portion of the geometry data for the IDB, as previously described, and has been a major undertaking by CSD and the engineering group involved for many years.

o Enhanced TIGER. The Navy-developed TIGER reliability, maintainability, and availability (R/M/A/) program has become a widely used standard of government agencies, the marine and other industries. Over 200 copies of TIGER have been delivered to this spectrum of user5 in the last 15 years. This fall will see the introduction of a significantly upgraded version of the program, version 8, which has now become the center of a series of R/M/A programs with increased capabilities. Some of the new features include: runs 10 times faster; ANSI 77 FORTRAN throughout; flexible array sizes; added spares/repair opt ions; input error checking; post processing graphics; improved documentation; and compatability with older versions of the input data format. Current users of the TIGER program will receive direct notice of availability of the enhanced version.

o ASSET Synthesis Model Standardization. The ASSET (Advanced Shio System Evaluation Tool) was originally conceived at DTNSRDC for their use in evaluating the application of new technology t0 shin design [11]. During its evolution, many program features were incorporated that made for flexibility in modifying the program for new technologies, such as: modular program construction; flexible command-driven input; well-defined internal data structure and management system. These features also proved very attractive from another)% viewpoint, that of serving as a common framework for developing ship synthesis models used during Feasibility Studies at NAVSEA. After two years of infusion, the ASSET version 2.0 program has blended the engineering approach of NAVSEA's DD08 destroyer-synthesis program with the Original ASSET program to produce a working prototype for future synthesis model development. This version of the program is currently undergoing acceptance testing at NAVSEA. A whale series Of similarly structured synthesis models for the most popular ship type5 is envisioned.

0 patran is a commercial product that serves as a pre and post processor for popular finite element analysis programs such as NASTRAN and GT STRUDL. It greatly reduces manual preparation of geometry-related information and provides color displays of stress levels.

0 PSS/E (Power System Simulator/Evaluator) is a commercial program that permits complete modeling and analysis of electric power systems. Commonly used in the electric power industry for simulating the characteristics of entire electric grids, it can be used far smaller systems such as ships.

o The TEMPLATE set of subroutines provides a standard mean of displaying graphic data to a wide variety of terminal types including those used at NAVSEA. We will be writing all new Graphics programs using this commercial package as a way of standardizing ou software development in this area.

o The Computervision (CV) system has been installed a NAVSEA headquarters for almost two years, currently having eight colo workstations and two central processing units. They were acquired primarily to evaluate commercial 3-D geometry modeling capabilities and have proven themselves as extremely powerful tools in this area They have been applied to several recent ship design project 5: the DDG-51 destroyer; SSN-21 submarine; and FFX frigate. Originally use on art experimental basis in parallel with the normal design met hod these specialized "turnkey" CAD/CAM systems will become mainstream activities On selected projects. The cv equipment is being used as prototype for evaluating a radically different approach to geometry modeling than the development of specialized programs that CSD ha been been sponsoring in the past. This is unfamiliar ground far bot NAVSEA and Computervision (and similar "turnkey" systems) because these systems have not been closely tied to engineering application programs in the past, but rather are production-oriented tools During the ship design process, an estimated 75% of the engineerin effort is devoted to analysis, 25% to geometry modeling. It is therefore essential that any modeling system be able to support a intimate interface with analysis. programs that require significant general purpose computing capability. The CSD project is currently investigating this issue.

Software Development Standard. Many government standard already exist for software development but almost all are concerne with tactical software, that is computer programs embedded in weapons systems. There is little guidance for the development of engineerin software, other than that it use FORTRON as the standard language, Enter the CSD Software Development Standard (SDS) [12]. This' modes (35 page) document contains the bare essentials for guiding the planning, programming, testing and documentation of NAVSEA engineering programs. Carefully distilled from thousands of pages O MIL-specs and other references, the SDS has been invoked in al software development tasks for the CSD project since November 1984, Appendices to the SDS include the two key reference5 that ar otherwise hard to locate. The Objective of issuing the SDS is t promote the development of quality software that performs t o expectations, is well documented and easier to support. While initially somewhat more costly to use than the older- "seat of the pants" program development approach, there is no doubt about the long term payoffs in reduced software maintenance costs and longer program life. Copies of the SDS are available directly from the authors.

Software Toolbox A key software productivity enhancing activity initiated this year is the development of a so called "software toolbox", a collection of commercial and in-house subrouting packages that speed and standardize the development of engineering

software. The TEMPLATE package mentioned previously is an example of a part of the toolbox that would fulfill the graphics requirements. Similar sets of subroutines are to be compiled for mathematical functions, plotting aids, document preparation aids, and program debugging and testing aids, to name a few of the categories in the CSD toolbox. The marine industry has recognized the value of a careful. approach. to software tool development and proposed some recommendations in reference [13]. Quality construction, documentation and support for the toolbox will be a major activity of the CSD project in coming years.

Digital Data Transfer.

The transfer of ship engineering information in computer sensible form between the Navy, engineering agents, and the shipbuilder5 has been a subject of increasing interest in the past two years. Among the potential benefits to be gained are: reduced errors and inconsistencies in the Contract Design package; shortened Detail Design time and cost; fewer downstream claims; easier transition to zone-oriented production techniques; return of engineering data for each ship in the "as built" condition to the Navy for improved service life support; linkage of engineering data to shipbuilding and logistics management computer systems in the shipyards and the Navy. Computer technology and interface standards have only recently given us the tools to attempt this with a high probability of success.

The types of products that are currently transferred between engineering activities take the form of two types of paper: text and drawings. Use of the ASCII (American Standard Code for Information Interchange) standard for character data has permitted the transfer of simple kinds of textual data for many years. Sophisticated page formatting or embedded figures cannot be transferred yet and there is little compatability among the word processors in use but there are signs that a more encompassing standard is emerging in this area in the form of DIF, Defense Information Format. Never-the-less, digital text transfer provides the least benefits from an overall ship design viewpoint because the data is not readily usable for engineering purposes even when available on the computer.

Of more direct use for engineering is the digital transfer of drawings. The IGES (Initial Graphics Exchange Standard) has been developed by the National Bureau of Standards in close cooperation with the CAD/CAM industry specifically to faster digital data transfer between dissimilar CAD computer equipment [14,15]. As shown in figure 5, an IGES transfer involves pre-processing an existing drawing in the native form on one CAD system to produce a digital version of that drawing in a standard format on a magnetic tape. The tape is then physically transferred to another vendors CAD equipment and post-processed to reconstruct the same drawing image in the native form 0f the receiving CAD system. In principle, all the accuracy and information is retained during the transfer, which avoids the problems encountered if it were loaded in manually from a paper drawing.

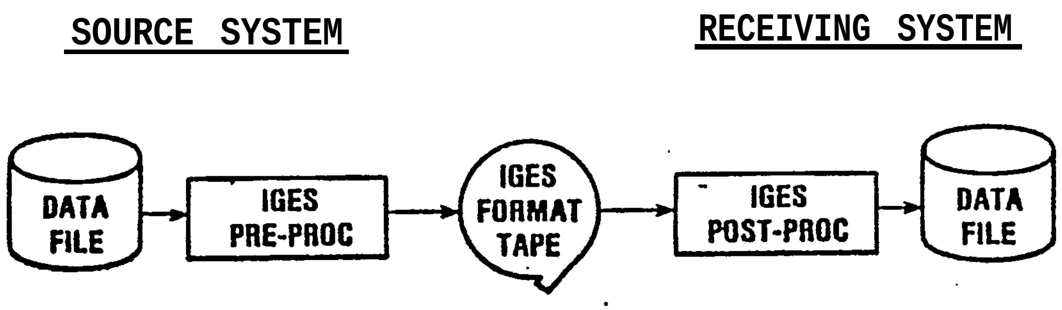


FIGURE 5. IGES Data Transfer Process

A recent test of the IGES capability was performed between several different brands of CAD equipment during the DDG 51 Contract Design effort and revealed many strength5 and weaknesses of the early pre/oost processors [16]. Despite this, the IGES standard is the only method that exists for performing these transfers and is actively supported by the Navy [l7]. With time, the IGES capabilities can be expected to mature and ultimately fulfill the intended function to a high degree.

Liaison With The Marine Industry, The interactions between the Navy and the marine industry relative to, CAD/CAM have grown substantially in the last three years as the overall interest level in computer aided engineering and manufacturing has increased. Since the demise of IREAPS, alternative communication channels have been cultivated, including:

o Active Navy participation in the SNAME groups concerned with CAD/CAM (Ship Design Panel #2 and Ship Production Panel #4) through regular presentations at panel meetings.

o DCGA (Defense Computer Graphics Association) symposium panel discussion, December 1984, chaired by one of the authors with Navy and marine industry representatives. Of special interest was the advanced application of computer and CAD/CAM techniques to the DDG-51 Destroyer project [18].

0 Ship design project support involvement by soecific shipbuilders on the DDG-51 and SSN-21 projects, particularly in the area of CAD/CAM and data transfer.

o Monthly newsletter distribution of CAD-related news by the CSD project office at NAVSEA to over 300 government and industry observers [13].

o Navy computer program dissemination by the CSD project office t0 qualified U.S. industries. Over 250 copies of computer programs were distributed in the past 10 months alone. The Abstracts of Computer Programs [20], widely distributed to Navy and industry in November 1984, summarizes the active library of NAVSEA's shiP design application5 programs. Copies are available from the authors.

The Navy in general and the authors in particular have a keen interest in maintaining close contact with the marine industry. We have met with dozens; of representatives and are attempting to foster- an open and productive interchange with the shipbuilding community for our mutual benefit.

FUTURE CPD/CAM DIRECTIONS FOR NAVY

The ability represent all forms of information digitally through the use of computers is revolutionizing the way we **do** business. Wireframes, Surfaces, and now solids provide a means to manipulate geometry in three dimensions previously not possible. Interaction by designers with computers through graphics provides a vehicle by which designs can be driven from a producibility and maintenance perspective, resulting in end products of superior quality. From a Navy standpoint, this means weapon system5 of increased capability at reduced costs which can be maintained and modernized much more readily than in the past. Thus, a ship weapon system can be maintained in a high state of readiness and be a viable system throughout it5 operational cycle. Coupled with data transfer standards, computers could free the engineering community of many of the problems of using paper as a means of exchanging data.

During the past three years, the Navy has become increasingly interested in the potential of CAD/CAM as a key element in the life cycle management of weapon systems. More recently, the U.S. Senate Appropriations Committee report on the Department of Defense Appropriations Bill, 1985, contained this except:

> "The Navy **is** instructed to report to the Committee on the potential expansion of computer aided design and manufacturing techniques at naval shipyards and engineering centers. "

The report also noted 30 percent reduction of targeted costs in private shipyards and that the Navy has invested 5 billion dollars in business related ADP systems but less than 100 million in CAD/CAM. The Committee is correct. Application of CAD/CAM technology **is** expected to produce substantial reduction of Navy material acquisition and logistic support costs.

The Navy is in the initial stage of an effort to realize the benefits of CAD/CAM technology. The potential program is being addressed now in POM-87 programming. In responding to the Chairman of the Senate Committee on Appropriations, Secretary of the Navy John Lehman stated in his letter:

"We are convinced, based on industry's experience, that CAD/CAM will result in significant savings to the Navy. We are reviewing candidates from a pilot program and expect to select one as a significant project by the fall of 1985. "[2]

In arriving at this conclusion, the Navy, under the direction c the Program Manager, NAVSEA Information Systems Improvement Program developed a three part report, including: overall Navy CAD/CAM experience, findings and organization; Naval SEA Systems Command (NAVSEA) CAD/CAM actions and plans; and other Navy CAD/CAM planning.

Overall CAD/CAM Experience, Findings and Organization

Past Navy CAD/CAM Experience. The Navy has monitored the technology and conducted small CAD/CAM efforts since 1364. The three principal past CAD/CAM efforts - all still ongoing - are the CSD shi design CAD program in NAVSEA headquarters, a small CAD/CAM program i Navy Laboratories, and the recent procurement of CAD/CAM equipment fc Navy Laboratories and three system commands under the CREDOS program As noted in the Senate report, investment in these Projects ha totalled approximately 100 million dollars. Past Navy experience ar private sector experience indicate that CAD/CAM technology can benefi the Navy importantly.

Findings. U.S. auto makers, during 1980-4, invested in CAD/CAM amount reported in the press as 60 to 80 billion dollars. During the first quarter of 1384, U.S. auto makers produced automobiles at a rat two percent greater than the 1978 rate with 23 percent fewer- workers and quality was substantially improved.

Table 3 lists other private sector data from 1983-4 industrial publications and a National Research Council (NRC) study. These dat confirm that CAD/CAM can produce substantial cost, time, and produc quality improvements. Reducing change orders and rework of faile parts and subsystems is an important source of cost reduction. The quality implications are important to Navy operational availability and reliability.

Table 3

OTHER PRIVATE SECTOR RESULTS

Company/Product	Labor	Cost	Labor	Factory Test Labor
	(percent reduction)			
From literature				
Rockwell International	-30		-70	
Messerschmidt (FRG)		-44	-25	
Nigaata/engines(Japan)		-67	-75	
Grumman	-66			
General Electric				-75

From NRC report				
Computers	-50		-84	-80
Dishwashers	-40			-70
Cutter5	-50	-76	-76	
Electronics	-38			

Navy CAD/CAM will be applied principally in the Naval Material establishment. NAVSEA CAD/CAM applications are expected to be half of the total Navy CAD/CAM applications, as measured by investment and return.

Organization of Navy CAD/CAM.. The Chief of Naval Material on 28 July 1383 assigned NAVSEA to formulate and manage, as lead systems command, a NAVMAT CAD/CAM program. The Commander, Naval Sea Systems Command in turn assigned the program responsibility to the Program Manager, Information Systems Improvement Program, PMS 303, who report directly to the Commander of NAVSEA. The title of the resulting, budding program in NICADMM (Navy Integrated Computer-Aided Design, Manufacturing , and Maintenance program), pronounced Nick Adam. A Navy CAD/CAM Liaison Group was established in 1983 and has been operating for one year. The group **is** chaired by the NICADMM Program Manager. Membership includes representatives of all five Navy system commands ; the Director of Navy Laboratories; and the Director, Strategic Systems Programs. The functions of the Group are to assist the Program Manager in managing the NICADMM Program, review standards and exchange related information.

NAVSEA Actions and Plans

The NICADMM Program will provide centralized management of Navy CAD/CAM; promulgation and enforcement of technical standards applicable to all Navy CAD/CAM; and centralized (fully competitive) procurement of standardized equipment and system software. Development of application systems will be decentralized. NICADMM currently includes NAVSEA applications, and planning is underway for expansions to other system commands. Whether to budget for other CAD/CAM applications as part of NICADMM or separately has not been decided. Development of other applications will follow one to two year5 behind corresponding NAVSEA applications development, to avoid duplication of pathbreaking costs and for other reasons cited later.

Relation to Other Functions and Technical Data Systems. Naval ship technical data re used typically for 35 to 45 years after the data are created. As indicated in Figure 6, design data for each naval ship class are created during! development of ship element systems and design of the lead ship of the class. Production planning is completed in parallel with the final design stage and is applied during ship construction. Instructions for shipboard operation and maintenance of equipment and shore-based and sea-based integrated logistic support (ILS) are produced during construction of the lead ship and applied during the service lives of the ships. Design and other data are changed during the service lives of ships as combat and other element systems are updated by alterations to the ships.

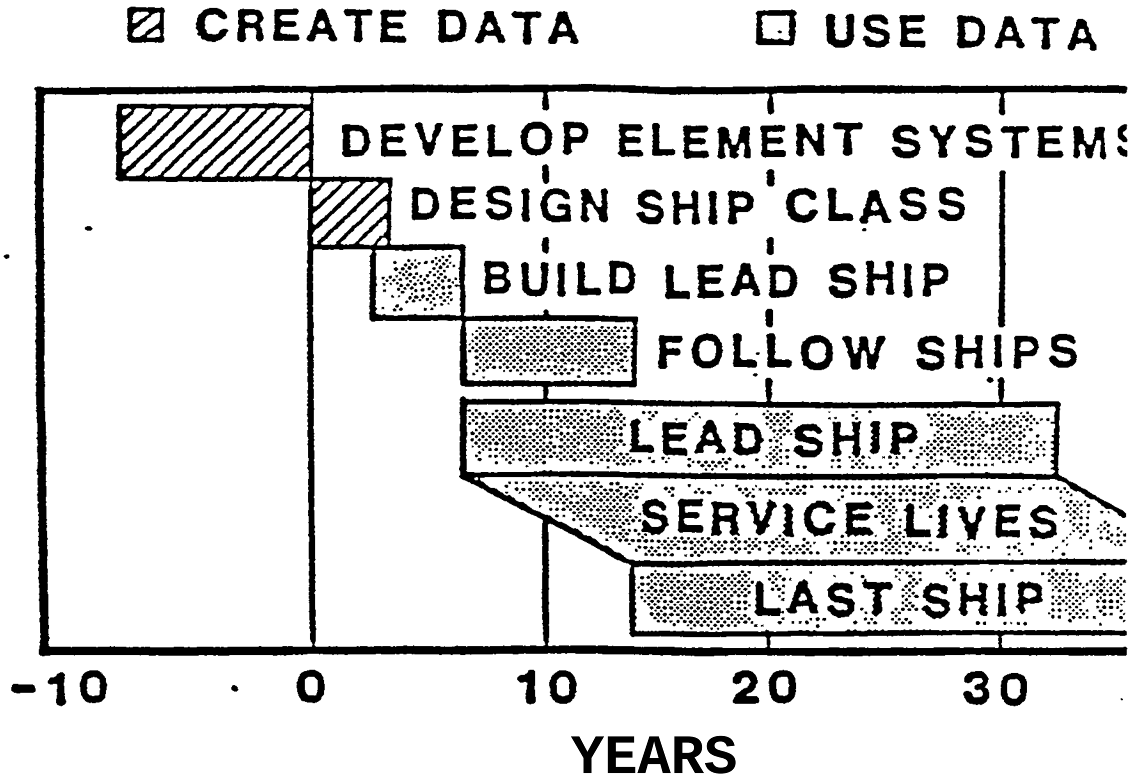


FIGURE 6. Life Cycle of Ship Class

Figure 2 indicates that NAVSEA CAD/CAM application systems wil be applied in ship acquisition, ship alteration, and shore-based shi maintenance. The figure also clarifies the relations among thes application systems, Navy standard technical information systems. ship acquisition, ship alteration, fleet operations, and logistic support.

investment and Net EFfect Projection. The NICADMM Program plan is based upon the following assumptions. First, CAD/CAM operating cost will replace substantially larger costs associated with current methods. Second, investment rate will determine the rate of realizin net cost i mprovement . Figure 7 applies to program performance ant illustrates conclusions drawn by applying private sector experians conservatively in a net effect computer model. the more assummotion are that, for each invest incerment mone of the cost imprument will be reaiized in the first program performance year after the increment is applied, 30 percent of the three-year return will be realized during the second program performance year, and 7.0 performancent the three-year return will be realized during the third program performance year and each successive year. Succeeding paracraphs explain the figure.

The curves in this figure reoresent net cumulative financial effect, that is, cumulative cost savings minus cumulative investment The curve assigned a probability of 0. 1 corresponds to a 7:i three-year payoff, which is optimistic. The curve assigned a probability of 0.5 corresponds to a 4:l three-year payoff, which is tyoical of CAD/CAM investments. The curve assigned a probability of 0.7

corresponds to a 2:1 three-year payoff, which is considered mediocre in the CAD/CAM community. For a wide range of probabilities, performance will lie between the two outer curves.

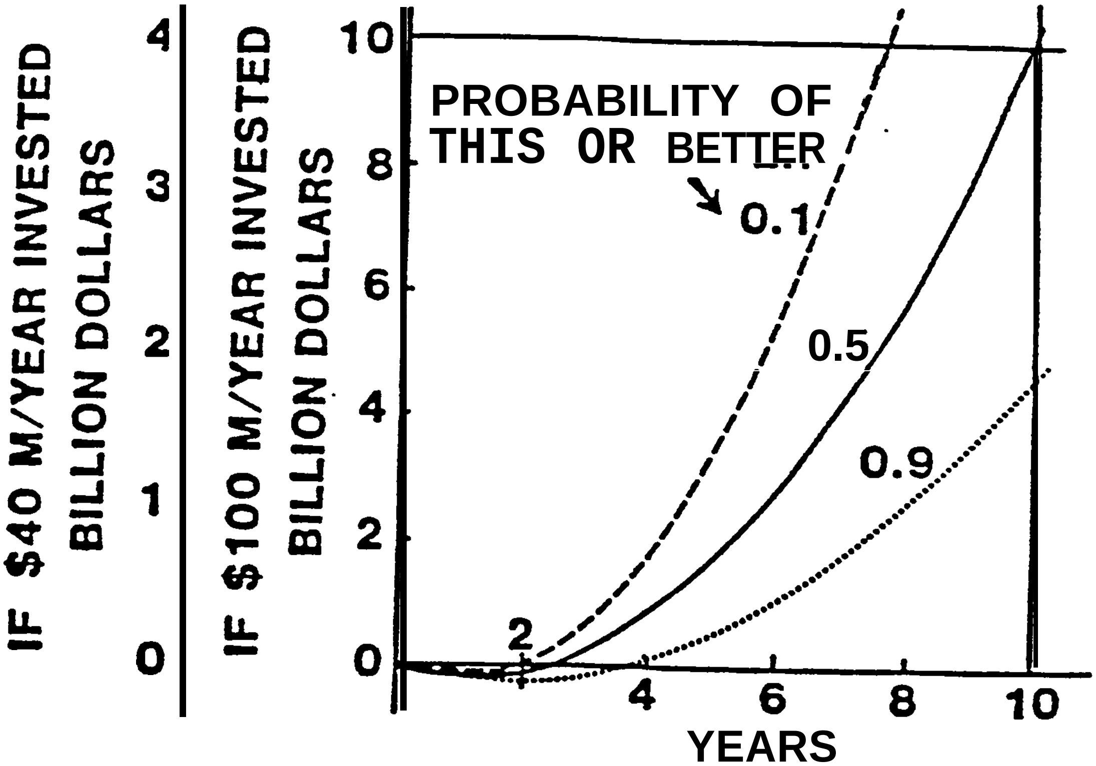


FIGURE 7. Net Financial Effect of CAD/CAM Investment

The break even Points, where the curves cross zero net effect, occur two to four years after the starting point. The net effect curves start down because the investment rates initially exceed the return rates. They bottom out where the return rates begin to exceed the investment rates.

The vertical scale depends upon the investment rate. For the most likely case (0.5 Probability curve) and if the investment rate is 100 million dollars per year, the projected ten-year net effect is plus 10 billion dollars (11 billion returned minus 1 billion invested). For the most likely case and, if the investment rate is 40 million dollars per year, the projected ten-year net effect is olus 4 billion dollars (4.4 returned, 0.4 invested). These two investment rates are high and low limits of recommended NICADMM program funding during the early years. An optimal rate in later years may be higher than 100 million dollars per year.

NAVSEA study, the NRC report, and other expert opinion sought by the Navy indicate that the foregoing projections should be wholly applicable to Navy material design, manufacturing, and maintenance. Testing of this key conclusion is being approached prudently.

NICADMM Program Status

A number of NICADMM Program management steps have been complete since the Chief of Naval Material assigned CAD/CAM program management to NAVSEA in mid-1383:

1. Liaison with the Air Force ICAM and Army ECAM programs has bee1 established.

2. The CAD/CAM Liaison Group has established the state of all Navy CAD/CAM act ions and adopted an overall Navy plan.

3. The NICADMM Program is included **in** the Department of the Navy Information System Plan dated June 1384.

4" A National Research Council advisory study (partially funded by NASEA but created with NRC's usual independence) has been publishec and calls for an immediate Navy-shipbuilder program.

5. A Mission Element Need Statement (first major top management decision paper for a new DoD program) has been prepared and is being reviewed within the Navy.

6. A program management plan (less appendices) has been prepared and reviewed by all potential participants. The acquisition plan and 17 other appendices to the program management plan are being prepared.

A brief summary of the technical status of Navy CAD/CAM follows.

1. The CÀD/CAM Liaison Group has reviewed intiatives by individual activity commanders and program managers. The initiatives were well **justified** and generally successful.

2. The status of on going CAD/CAM equipment installations under the CAEDOS program in systems commands' activities as of September 1981 was:

SYSCOM	Activites .	Planned	Installed	Percent
NAVSEA	13	$17.8 M	611.8 M	66
NAVAIR	13	7.0	6.2	83
NAVFAC	14	8.9	8.5	36

This equipment was procured from the Navy Laboratories' CAEDO$ contract administered by Naval Weapons Center, China Lake, California.

3. Results to date, in the affected NAVSER areas, show design costs down 48, percent, two-dimensional 1ayout costs down 28 percent, drafting costs down 42 percent, and cost of preparing bills of material down 20 to 50 percent.

4. More importantly, engineers in 40 Navy activities are being trained to apply CAD/CAM. The training effort is more than paying far itself, but that fact is less important than laying the foundation for larger pains.

5. A second, larger CAD/CAM equipment procurement for all systems command5 is being planned by the NICADMM program office.

Data- Exchanoes. The IGES specification previously noted has become a de_ facto national standard. IGES is open ended in the additional conventions cart be added, Just as sooken languages grow. NAVSEA invoked IGES in August 1984 for all naval shipbuilding and is planning shipbuilding additions to the IGES conventions. Shiobuildens welcomed the IGES requirement and concur in the need for additional shipbuilding conventions. The Navy invoked IGES as the standard for all intra-Navy and Navy-contractor CAD/CAM data exchanges in the Naval Material establishment in February of 1985

NICADMM Program Technical Plan. The NICADMM technical plan has part5 affecting only NAVSEA activities (principally naval shipyards; naval ordnance plants; suoervisors of shipbuilding, conversion, and repair; and engineering centers). It also has parts affecting both NAVSEA activities and private shipyards and other parts affecting all Navy CAD/CAM. Based ***upon*** lessons from the private sector and advice from consultants with extensive CAD/CAM implementation experience, the NICADMM technical plan requires intiation of two preparatory steps before undertaking major program performance. Funding decisions being made currently may affect the schedule. The schedule will become firm after the corresponding funding decisions are made.

Standards and Selectina Planningl Criteria and DevelopmentThe technical plan for the first preparatory steo has; two parts. The first, part is to select and adapt from successful CAD/CAM programs the following `standards for all Navy CAD/CAM.

System Software and and Equipment	Application Methods
Data management system	Application analysis
Operating systems	Application design
Languages	Programing
Graphic software	System testing
Software tools	Documentation
Mainframes	Implementation
CAD equipment	Rcceptance
Professional computers	Evaluation
Drafting equipment	Maintenance
IGES (done)	Alteration

The second part of the first preparatory step is t0 establish -criteria for selecting NAVSEA application development increments. The primary aim5 are to advance total production capabilities of NAVSEA activities (vice creating islands of automation) and obtain early payoffs. There are an abundance of candidate CAD/CAM applications. The need is to select and schedule for development the combination that most rapidly will reduce the tar-get costs and the time periods ships are in shiyards, and improve product quality. Performance must proceed via incremental expansion of a nucleus system. Selection of the nucleus system is a critical factor.

A substantial amount of planning is involved. The Navy' must st ud y for the affected activities--production cost factors, schedule critical paths, and product quality factors; existing relevant CAD/CAM systems; for each candidate development -- the investment amounts, development schedules, and expected benefits; interrelations among candidate developments; and the relations of various combinations of candidate developments to overall cost, time, quality, and i vest ment effects. This planning will be performed in a series of iterations, each reducing the number of candidate developments.

The NICADMM technical plan for the second preparatory step is to perform more detailed planning, evaluation, design, and scheduling of selected candidate NAVSEA applications. The evaluation criteria will be net effect on quality, cost, and time; invest ment profi le; return.. (benefits) profile; and state of preparedness to undertake each increment. The end product of this planning will be detailed plans far the first four to six program performance years and tentative plan5 for later years.

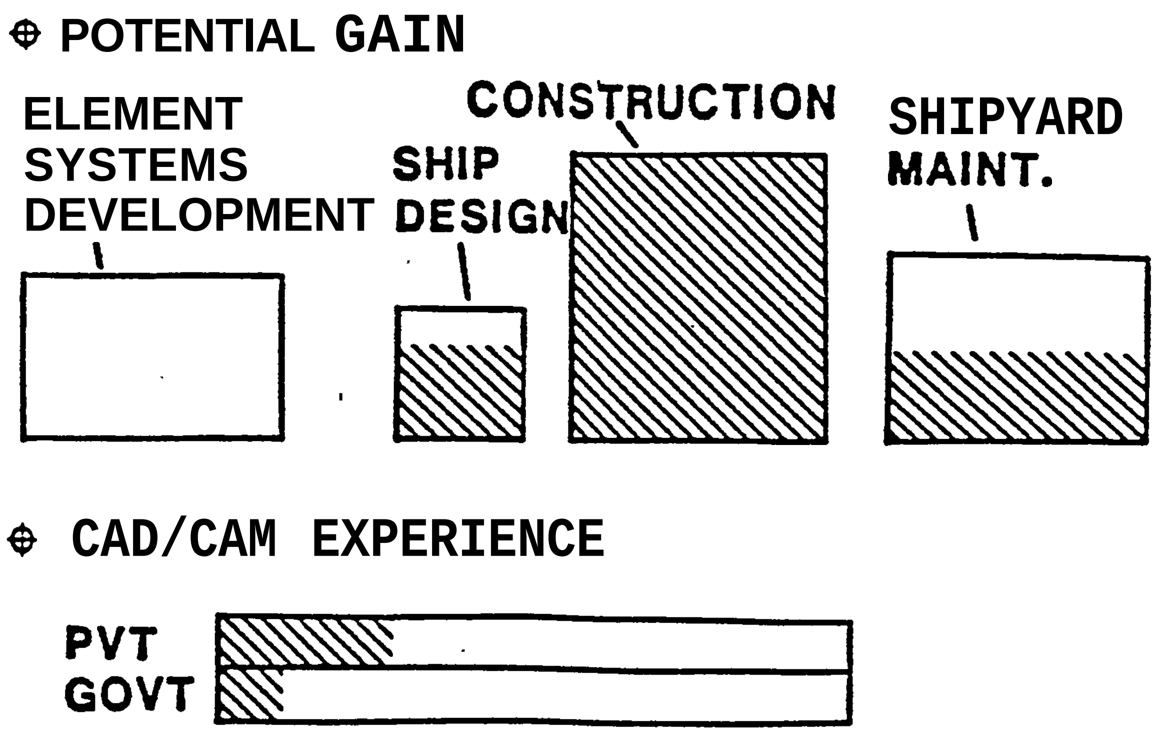


FIGURE 8. Private Shipyards' Role

Private Shipyards' Role and Data Ease Design. The sines of boxes in the upper part of Figure 8 indicate roughly the relative cost improvements obtainable in each area, except that cc& improvement in element systems development has not been estimated. NAVSEA applications effort during the first several years will focus upon ship design, ship construction, and ship maintenance. The shaded parts of the-corresponding boxes-indicate private shipyard operations. The unshaded parts signify operations of government=owned facilities.

The bottom part of Figure 8 reflects the fact that private shioyards have accrued more CAD/CAM experience than NAVSEA activities. NICADMM Program execution has and will include seekinq advice and assistance from oraganizations with with greater CAD/CAM experience including private shipyard;.

As indicated in Figure 6 greater cost impromemts in naval ship design, construct ion, and maintenance can be obtained in private shipyards than in NASEA activities. In addition, the major parts of the data base (technical data describing ships, construction plans and ILS plans) are created during the latter stages of ship design and during construct ion, which are both performed by private shipyards.

The next step after IGES in a Joint Navy-shipbuilder effort must be to (1) select suitable data management software systems (being performed by NAVSEA) (2) define data base content - after the ships are in the fleet, at the end of construction, and at the ends of various design stages - and (3) define methods for creating the required content. The data base design will vary for- different production systems, that is, different shipyards building and/or maintaining differ-ent ship types, but the first complete design will be mostly (70 to 90 percent) reused in subsequent naval and private shipyard applications. The alternatives are to define a partially standardized, Navy-initiated data base design, at a cost of 6 million dollars, or incur indirectly the greater cost of each private shipyard's separately developing a shipbuilding data base design. Good cost estimating data for data base design and development are available for GM and Boeing.

Because the Navy no longer operates a building shipyard, the data base design effort must be performed mostly by two of more private shipyards, with NAVSEA participation for tasking and compodinatictn and to cope with the fact that the results will involve proprietary information that private shipyards will not be willing to exchange with each other. This effort will include the needed IGES extensions and several other required technical elements (definition of drawing layers, group technology, and other CAD/CAM-peculiar factors).

Other Navy CAD/CAM Planning

Navy Laboratories will continue their ongoing limited CAD/CAM efforts. The major additions will occur in the Navy's system commands. All Navy systems commands will develop CAD/CAM programs. As explained earlier, the Navy will apply the standard developed in the NICADMM Program to all Navy CAD/CAM.

Naval Air Systems Command. The Naval Air Systems Command (NAVAIR) program is expected to be the second largest Navy CAD/CAM program. It will be the most complicated to formulate because of the reouirement for extensive liaison with the Air Force and the aerospace industry, which already has major CAD/CAM systems. The NICADMM program office is assisting NAVAIR in itiating required planning. As indicated earlier, 13 NAVIR activities are using CAD/CAM systems and training engineers.

Naval Facilities Engineering Command. The Naval Facilitie Engineering Command (NAVFAC) has formulated a CAD/CAM program. I reflects the state of CAD/CAM in the architectural, engineering an construction (AEC) industry.

The AEC industry is moving rapidly in CAD apolicat but but has few CAM applications The Design/C Giants 1983 (sevent annual) survey indicated that, of the 220 largest AEC firms, 3 percent now use CAD systems and arl additianal 26 percent plan t purchase such systems in the near future. AEC firms using CAD system have achieved improve design analysis, better design quality, and, faster completion of projects . The accumulation of design data base also will enhance building renovatians and life cycle operat ing and maintenance. Most of this progress has occurred during the past thre years. Its is expected that, when the AEC industry has sufficient experience to produce net effect data, the results will be similar t the results for other CAD applications.

The NOVFAC CAD/CAM program budget will be smaller than the NAVSE NICADMM Program budget for a number of reasons. First, the NAVFA Program does not encompass major CAM elements, and will not do s until the AEC industry advances to that point. Second, universities and industry have produced many civil engineering software package than can be applied by NAVRAC Third, NAVEFAC has established effective liaison with the Army Corps of Engineers to avcli duplication of work and share advances.

Naval Space and Warfare Command The Naval Space and Warfar Command CAD/CAM program necessarily will lag behind the NAVSE programm The electronic systems acquired are installed in shies aircraft, and shore stations. Ship installations are the larges segment. Prime contractors have extensive CAD/CAM experience and Spac and Warfare Command has a strong computer systems capability. Th Space and Warfare Command CAD/CAM systems however will feed into the NAVSEA, NAVAIR, and NAVFAC CAD/CAM systems, and the latter are not ye defined. It is anticipated that this command will make rapid programs after the foundation has been prepared in the NAVSEA application.

NAVAL Supply Systems Command. The Naval Supply Systems Comman (NAVSUP) is the lead system command for Navy Standard TEchnical Information Systems, and has corresponding Triservice responsibility The relation between these systems and CAD/CAM systems was illustrate in Figure 7 and was explained earlier in the presentation of tha figure. Current related NAIVSUP effort is focused on this asoect its responsibilities. Navy Standard Technical Information Systems and a related but seoarate budget .item. NAVSUP will address its international CAD/CAM applications at a later time. NAIVSUP' s most important current contribution to overall Navy CAD/CAM effectiveness is to assure a has fit between NICADMM applications and Navy Standard Technica Information Systems.

CONCLUSION

The National Research Councils report on shipbuilding productivity [21] strongly recommended Joint Navy and industry development of common engineering data bases and CAD/CAM systems t0 facilitate achievement of this goal. As you can see, the Navy is taking an active role in helping to shape the future of computer applications to the engineering functions for the ship's entire life cycle primarily through the CSD and NICADMM programs already noted. These intiatives are based primarily on the premise that CAD/CAM technology can be utilized to automate all the functions in the product development process as shown in Figure 3 . There are many problems, which require solutions. Three aspects of these programs will become increasingly important in this regard: setting: standards with industry for the exchange of engineering data; acquiring the software anti hardware tools for development and handling of this data; integrating and operating a Navy-wide engineering data base system system throughout the life cycle of each ship. The real driver behind these is, of course, the definition of the engineering data base itself.

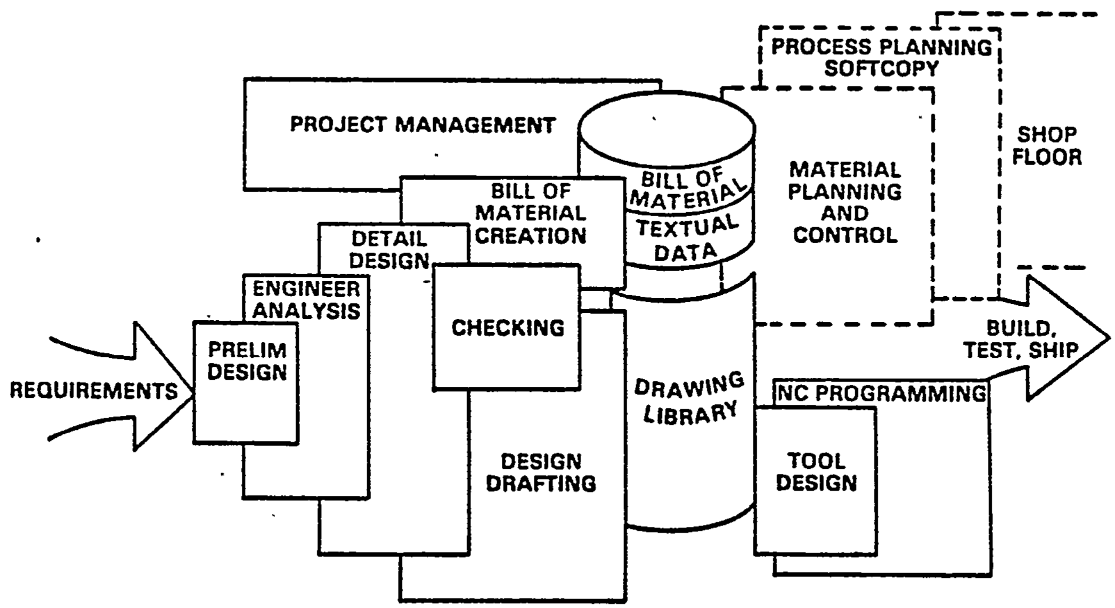


FIGURE 9. Product Development Process

The current state-of-the-art in geometry-oriented data transfer is centered about the digitization of current paper-based engineering products. The IGES specification is the prime example of this approach. However, it is extremely. difficult to accurately and consistently define a S-dimensional object like a ship with a set of 2-dimensional drawings. Drawings are also not directly usable for automated production techniques. Even if completely dimensioned-3 and self consistent from view to view and drawing to drawing5 which is a

rare occurrence, drawings do not define what is between the sections that are shown on each sheet. In other words, what is missing are the "rules of interpolation" for determining the value of any point in the third dimension. This lack of definition is particularly acute when complex shapes are involved, such as the ship's hull, many of the structural members and virtualiy all of the equipments. It was for this reason that scaled "half models" of the ship's hull form were used by naval architects during the days of sailing vessels to communicate to the shipbuilder what hull shape was desired. Thus, drawings should be thought of as matters of convenience, merely projection of three dimensional objects into two dimensions, a far cry from the full definition of the physical object. Ultimately, what is desired is not digital versions of 2-dimensional drawings, but instead, a digital representation of the entire ship containing complete S-dimensional geometric design and manufacturing information. This body of data has come to be known as the ship "product model", although a rigorous definition does not exist. It would include full geometric information and attributes of that geometry in sufficient detail to construct the product. It would contain the manufacturing information about the ship as actually constructed in a form that would permit complete replication of parts for repair and overhaul work thoughout the ship's life. Computers provide the only practical mechanism for defining and transferring product models.

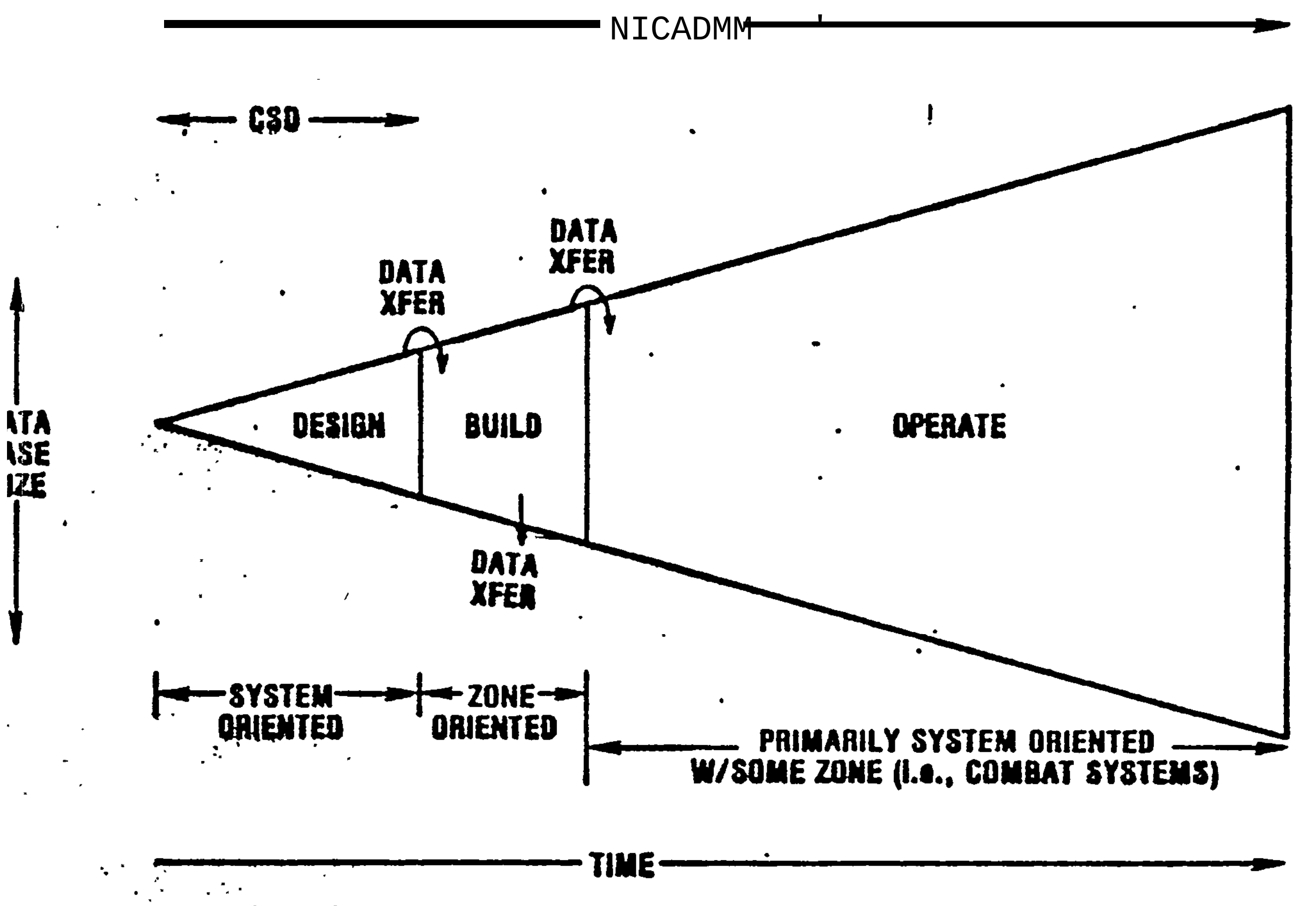


FIGURE 10. Product Model Data Base Life Cycle

The product model is not a stagnant body of data but evolves and grows throughout the life of the ship as depicted in figure 10. At key junctures, the product model would be transferred between the Navy and the shipbuilder, at the end of Contract Design and again at the end of construction, or between lead and follow shipbuilders at the end of Detail Design. These are the main data transfer points at which the definition of the product model needs to be standardized throughout the industry. The engineering methods and data bases used within the "design", "build" or "operate" phases could be left undefined, able to be tailored to the specific needs of each agency or shipyard. This would provide us with a common language for data exchange at these interfaces, while permitting almost unlimited flexibility for individual activities to do what is best for them.

The application of computer aids for engineering design, manufacturing and service life maintenance of Navy ships has been a continuing priority for the Navy and the marine industry for many years. The Navy has developed an organization and plan for major expansion of computer aided design, manufacturing, and maintenance encompassing overall management of Navy CAD/CAM, NAVSEA CAD/CAM applications, the Navy-shipbuilder interface, and NAVFGC CAD apolications. 'This plan will be executed as soon as related funding decisions are made.

Only recently has the power of the computer actually started -to approach our vision5 for its usefulness. The next few years will be crucial ones for setting the standards and developing the tools to fully harness this power. There are opportunities here that may not come again and must not be passed by. Capitalizing on them will take a dedicated, Joint effort on the part of the entire industry.

[2w

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NATIONAL SHIPBUILDING RESEARCH PROGRAM
1985 SHIP PRODUCTION SYMPOSIUM

TUESDAY, SEPTEMBER 10

6:00 PRE-REGISTRATION SEAVIEW LOBBY
9:00PM

7:00 RECEPTION SEAVIEW FOYER
9:00PM

WEDNESDAY, SEPTEMBER 11

7:30AM REGISTRATION REGENCY LOBBY
4:00PM

9:00AM GENERAL SESSION REGENCY ABC

Session Chairman: Ed Peterson
Todd-Pacific Shipyards

OVERVIEW OF NSRP:
Jesse Brasher
Chairman, Ship Production Committee

KEYNOTE ADDRESS:
The Honorable James F. Goodrich
Undersecretary of the Navy

KEYNOTE ADDRESS:
Mr. Tim Colton
Vice President - Business Development,
Capital Marine Corporation

KEYNOTE ADDRESS:
Mr. John H. Leeper
President
Phillips Cartner & Co., Inc.

12:00PM LUNCHEON REGENCY DEF

1:30 CONCURRENT SESSIONS
3:00PM

SESSION 2A REGENCY A

FLEXIBLE MANUFACTURING

Session Chairman: James Acton
Todd-Pacific Shipyards

-OVERVIEW OF SF-10
James Acton, SP-10 Chairman

-A COMPUTERIZED ROBOT SELECTION SYSTEM
Harilyn S. Jones, Virginia Polytechnic Inst.

-ISLANDS OF AUTOMATION
Robert J. Bellonzi, Bath Iron Works

-COMPUTER-OPTIMIZING OF BEVEL ANGLES FOR WELDED PIPE JOINTS
Harry W. MERGLER, Case Western Reserve Univ.

-APPLICATION OF FLEXIBLE AUTOMATION TO SHIP CONSTRUCTION
John Sizemore, Ingalls Shipbuilding

SESSION 2B REGENCY B

FACILITIES & ENVIRONMENTAL EFFECTS

Session Chairman: Richard Price
Avondale Shipyards

-OVERVIEW OF SP-1/3 PANEL
Richard Price, SP-1/3 Chairman

-CRANE ANALYSIS
Walter Manning & Dieter Weinreich, Emscor Inc.

-GROUP TECHNOLOGY/FLOW APPLICATIONS IN PRODUCTION SHOPS
William S. Oakes, NASSCO

-WEB FABRICATION LINE: RESULTS OF A FEASIBILITY STUDY
Michael Tomzig, Oxytechnik Systems Engineering

-THE N&STING AND MARKING OF SHIP PARTS CUT FROM STEEL PLATE
Harry Hooper, Consultant to Avondale Shipyards

3:30 CONCURRENT SESSIONS
5:00PM

SESSION 3A REGENCY A

SURFACE PREPARATION AND PAINTING

Session Chairman? John Peart
Avondale Shipyards

-OVERVIEW OF SF-023-l PANEL
John Peart, SP-023-1 Chairman

-0VERCOATING OF INORGANIC ZINC PRIMERS FOR UNDERWATER SERVICE
George A. Gehriny, Jr., Ocean City Research

-EVALUATION OF WET BLASTING FOR SHIP APPLICATION
Dr. Bernard Appleman, Steel Structures Painting Council

-FLAME SPRAYED COPPER ALLOY COATING FOR UNDERWATER SERVICE: CORROSION CONSIDERATIONS
Louis M. Riccio, Copper-Lok, Inc.

SESSION 3B REGENCY B

EDUCATION AND TRAINING

Session Chairman: Prof. Howard M. Bunch
University of Michigan

-OVERVIEW OF SP-9 PANEL
Howard Bunch, SP-9 Chairman

-AN LIAMINATION OF TWO MULTI-SHIPYARD COOPERATIVE TRAINING PROGRAMS
OF Alvin J. AbramS, Data Design Laboratory

-EVALUATION OF CRAFT TRAINING CONCEPTS USED BY EUROPEAN SHIPYARDS
Paul W. Vickers, University of Michigan

-THE CERTIFICATE IN MANUFACTURING ENGINEERING - SHIP PRODUCTION: A NEW PROGRAM FOR SHIPYARD EMPLOYEE SELF-INSTRUCTION
William D. McLean, Society of Manufacturing Engineers

5:00 7:00PM RECEPTION SEAVIEW FOYER

THURSDAY, SEPTEMBER 12

8:00AM 2:00PM REGISTRATION REGENCY LOBBY

8:30 **10:00AM** CONCURRENT SESSIONS

SESSION 4A REGENCY A

INDUSTRIAL ENGINEERING

Session Chairman: J.R. Phillips
Bath lron Works

-OVERVIEW OF SP-8 PANEL
Maurice Conningham, SP-8 Secretary

-COMPUTERIZED APPLICATION OF STANDARDS
Carol I. Edwards & Charles C. Meador, Newport News Shipbuilding

-INCREASING PRODUCTIVITY THROUGH METHODS IMPROVEMENT
James R. Ruecker, NASSCO

-THE RELUCTANCE TO IMPLEMENT **NEW** TECHNOLOGY: INDUSTRIAL ENGINEERING'S ROLE
Marilyn S. Jones, Virginia Polytechnic Inst.

-IMPROVING SHIPYARD PRODUCTIVITY THROUGH THE COMBINED USE OF PROCESS ENGINEERING AND INDUSTRIAL ENGINEERING METHODS ANALYSIS TECHNIQUES
Tommy L. Cauthen, Ingalls Shipbuilding

SESSION 4B REGENCY B

HUMAN RESOUHCE INNOVATION

Session Chairman: Frank Long
Bethlehem Steel

-OVERVIEW OF SP-5 PANEL
Frank Long, SP-5 Chairman

-MULTI-SKILLED SMALL WORK TEAMS IN A ZONE CONSTRUCTION ENVIRONMENT
ban Stravinski, **NASSCO**

-LABOR-MANAGEMENT COOPEHATION IN THE DESIGN AND OPERATION OF EMPLOYEE INVOLVEMENT
Stephen Sullivan, Bethlehem Steel Corp. and David Case, Industrial Union of Marine Shipbuilding Workers of America, Local 33 Bethlehem Steel Corp., Sparrows Point

10:30AM 12:00PM CONCURRENT SESSIONS

SESSION 5A REGENCY A

WELDING

Session Chairman: Benjamin C. Howser III
Newport News Shipbuilding

-OVERVIEW **OF** SP-7 PANEL
Benjamin Howser, SP-7 Chairman

-TRACKING SYSTEM FOR AUTOMATIC WELDING
James Cameron, Electric Boat Division, General Dynamics

-TWISTED WIRE NARROW GAP WELDING
Frank B. Gatto, Puget Sound Naval Shipyard

SESSION SP **REGENCY B**

DESIGN/PR0DUCTION INTEGRATION

Session Chairman: Baxter Barham
Newport News Shipbuilding

-OVERVIEW OF SP-4 PANEL
Baxter Barham, SP-4 Chairman

-ENGINEERING MANAGEMENT FOR ZONE CONSTRUCTION OF SHIPS
Thomas Lamb, Tacoma Boatbuilding Co. Inc.

-PRODUCIBILITY AS A DESIGN FACTOR IN NAVAL SHIPS
Lcdr Michael **D.** Boaworth & Capt Clark Graham, Massachusetts Institute of Technology

12:00PM LUNCHDON REGENCY DEF

1:30 3:00PM CONCURRENT SESSIONS

SESSION 6A REGENCY A

MARINE INDUSTRY STANDARDS

Session Chairman: J.R. Phillips
Bath Iron Works

-OVERVIEW OF SP-6 PANEL
Tom O'Toole, SP-6 Secretary

-STANDARDIZATION FROM MARINE EQUIPMENT SUPPLIERS PERSPECTIVE
Parker L. Hay, Hyde Products

-MAKING THE RIGHT CONNECTION - PIPING SYSTEMS PAST, PRESENT, AND FUTURE
Dave Kelly, Deutsch Metal Components

-SHIPBUILDING STANDARDS OF THE U.S. AND THE WORLD
Robert B. Toth, R.B. Toth Associates

SESSION 6B REGENCY B

OUTFITTING **AND** PRODUCTICN AIDS

Session Chairman: **Louis** D. Chirillo
L.D. Chirillo & Associates

-OVERVIEW OF SP-2 PANEL
Louis Chirillo, SP-2 Chairman

-A **NEW** SHIPBUILDING MEASUREMENT TOOL - PHOTOGRAMMETRY FOR MEASURING CIRCULARITY OF SUBMARINE HULLS
Lawrence R. Jacobsen & Philip N. Biondo, Electric Boat Division, General Dynamics

-APPLICATION OF ZONE LOGIC AND OUTFIT PLANNING CONCEPTS TO OVERHAUL, MODERNIZATION AND REPAIR OF U.S. NAVY SHIPS
Dennis C. Moen, Puget Sound Naval Shipyard

3:30 CONCURRENT SESSIONS
5:00PM

SESSION 7A REGENCY A

NAVY PRODUCTION AND REPAIR

Session Chairman: John Freund
Naval Sea Systems Command

-NAVY SHIP DESIGN & PRODUCTION INTERFACE
P.A. Gale & Capt. B.F. Tibbitts, U.S. **Navy**

-EXPANDED PLANNING YARD CONCEPT & CONFIGURATION ACCOUNTING
Capt. A.R. Karn & Cdr. E. Runnerstrom, U.S. **Navy**

-ADP DIRECTIONS FOR NAVY
Capt. J.F. Leahy III, & J.C. Ryan, U.S. Navy

SESSION 7B REGENCY B

OUTFITTING AND PRODUCTION AIDS (Cont.1

Session Chairman: Louis Chirillo
L.D. Chirillo & Associates

-PIPE FABRICATION TO SUPPORT MODERN SHIP CONSTRUCTION METHODOLOGY: THE IMPLEMENTATION OF **AN** INTEGRATED FABRICATION CONTROL PHILOSOPHY IN A MODERNIZED SHIPYARD PIPE SHOP
David Saginaw II, NASSCO

-ZONE OUTFITTING IN A CANADIAN GREAT LAKES SHIPYARD (THE FIRST FOUR YEARS)
Alan J. Telfer, Collingwood Shipyards

5:00 RECEPTION SEAVIEW FOYER
7:00PM

FRIDAY, SEPTEMBER 13'

TOUR OF LOCAL FACILITIES

--Todd Pacific Shipyards
--Howard Hughes' "Spruce Goose"

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